An Evaluation of

Basal Metabolic Data

for Infants in the United States

Home Economics Research Report No. 18

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

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by Dorothy Worstell Sargent

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Washington, D.C. Issued June 1962

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C. - Price 30 cents

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By Dorothy Worstell Sargent, *Human Nutrition Research Division, Agricultural Research Service*

The analyses made herein are an extension of those in Home Economics Research Report No. 14, "An Evaluation of Basal Metabolic Data for Children and Youth in the United States" (Sargent, 1961). In the preceding publication basal metabolic data obtained on children 2 years of age to 16 years for girls and to 18 years for boys were analyzed. In this publication data obtained on infants between birth and 2 years are analyzed. However, data up to 3 years are included from one study (Lee, 1952), since they were obtained under the same conditions.

The data for infants have been analyzed and reported separately, because the conditions under which heat production measurements were obtained for infants differ from the standardized conditions used in obtaining basal metabolic measurements for older children and adults. In infants measurements of minimal heat production were made after feeding and while asleep in order to obtain muscular repose. Thus, so-called "basal" heat production measurements on infants (as reported herein) are not strictly comparable to those for older children obtained when awake and at least 12 hours after eating. Many investigators are of the opinion that the stimulating influence of a small amount of food is offset by the depressing effect of sleep (Murlin, 1932). However, Benedict and Talbot (1921) were somewhat limiting in their conclusion: "It is probable that these to a certain extent neutralize each other."

Although these heat production measurements on infants may not represent a true basal (minimal) value, the term "basal" will be used herein since this is the basic value used for estimating total energy needs. The daily required intake may be estimated by adding to this basic value the caloric needs for growth, muscular activity, and the caloric loss in excreta. The specific dynamic action of food is included in the basic value, at least, in part, since nonfasting data are used.

Differences in apparatus and procedure among the investigators are less varied for infants than for older children. A respiration chamber is usually employed for measuring heat production of infants, because the apparatuses using a mask or mouth piece and nose clip, often used for older children, are not suitable for infants (*see* Higgins and Bates, 1930).

Since no restraint is placed on the infant within the chamber and because the measurements are usually made to coincide with the usual nap period, the effect of apprehension or inexperience of the infant with regard to the procedure or apparatus is not considered a factor affecting measured heat production of infants (*see* Karlberg, 1952). Furthermore, there is less variation due to muscular activity, since this was almost always recorded either by observation or by graphic records (*see* Benedict and Talbot, 1912) and sometimes by both methods; and the records showing more than an occasional movement were discarded.

The subject of reference bases used for expressing basal metabolism was discussed in detail in the previous publication (Sargent, 1961, section III). However, weight is more frequently used as a standard of reference for infants, since estimating surface area from formulas is less satisfactory for infants than for adults. Karlberg (1952) has recently constructed a nomogram for determining body surface from weight and height, based on the determination of "electrical capacitance surface" of 130 infants.

Accurate norms, or standards, of basal heat production are valuable in infancy, because this is the age period of most rapid growth in which the relative nutritional needs are greater than at any other age period. These standards are needed for estimating optimal food energy requirements for normal growth and development, especially in newborn and premature babies, since appetite is not always a sound criterion to use. Macy and Hunscher (1951) demonstrated, from studying the relation of caloric intake to growth in 4- to 9-year-old children, that a difference in the daily intake of as few as 10 Calories per kilogram of body weight may mean the difference between success or failure in making satisfactory growth progress.

I. Sources of Data

Although metabolic measurements on infants were reported as early as 1877 in Europe (for review of the early literature, *see* Benedict and Talbot, 1914b), the first measurement of heat production on infants in this country were made 50 years ago by Carpenter and Murlin (1911) at the Carnegie Institution of Washington. By deducting the measured metabolism of the mother alone from that of the mother and infant measured together in a bed calorimeter, these investigators obtained heat-production values for three newborn infants.

Howland (1912) paved the way for extensive observations on heat production of infants by demonstrating that the results obtained from short periods in the indirect calorimeter were in agreement (within 2 percent) with those obtained with the more expensive and elaborate direct calorimeter. Subsequently, investigations were begun by Benedict and Talbot with the respiration chamber in the Nutrition Laboratory of the Carnegie Institution of Washington in Boston, and by Murlin and associates at Cornell Medical College, New York, with a "constant-temperature tight inner chamber connected with the Benedict 'universal respiration apparatus'."

Many of the early measurements made by Benedict and Talbot (1914a; 1914b) were made on underweight infants; some had simple digestive disturbances and some were in the convalescent stage of a disease. A few observations were made on distinctly pathologic cases. However, those reported in 1915 (on newborn infants) and in 1921 are believed to have been obtained on healthy infants. Although some were below the average weight for their age, no clinical abnormality was detected from a physical examination. Thus, the data were separated into two nutritional groups for analysis: "Healthy infants" and "Undernourished infants." A third group consisted of measurements on "Premature infants," which were analyzed separately because of the difference in physiological development.

Pertinent information regarding the available data on basal metabolism is summarized in table 1 for these three groups of infants. The measurements on infants were from the following laboratories or groups of investigators:

(1) The reports of Benedict and Talbot from the Carnegie Institution, and the Massachusetts General Hospital, Boston, supplied a large portion of the available data for this report both for Healthy infants and for Undernourished infants. Talbot and associates (1923) also contributed data on Premature infants.

(2) Murlin and associates (Bailey and Murlin, 1915; Murlin and Hoobler, 1915) began investigations on the metabolism of infants in 1913 at the Physiological Laboratory of Cornell University Medical College, New York. This work was continued by Murlin at the University of Rochester (*see* Murlin *et al.*, 1925; and Marsh and Murlin, 1925).

(3) Workers at Columbia University, New York City; Marine and associates (1922); and later Benjamin and Weech (1943) investigated the basal metabolism of infants by making repeated measurements over a period of 1 month or longer.

(4) A series of papers on basal metabolism of children and infants has been published by the Department of Pediatrics, Cornell University Medical College. In 1927 data on two infants were reported by Levine and associates. These data, along with others, were reported in a biometric study in 1931; therefore, only the latter reference is used. Marantic infants were subjects of many early investigations of this group (Levine *et al.*, 1928a; Watt, *et al.*, 1932), but more recently they studied premature infants (Gordon and Levine, 1936; Gordon *et al.*, 1940; Dann *et al.*, 1942; and Day, 1943). Dann *et al.*, also reported data for two full-term infants.

(5) Clagett and Hathaway (1941), working at New York State College of Home Economics, Ithaca, measured the basal metabolism of eight normal infants (including three pairs of twins) at approximately monthly intervals for periods of 5 to 10 months.

(6) The more recent data from the Child Research Council, Denver, Colo., make a noteworthy contribution to this report, supplying data of about the same magnitude as that of Benedict and Talbot. Measurements on normal, healthy infants 1 month of age were begun in 1943 and repeated at approximately 3-month intervals. Data for individual measurements were reported by Lee (1952). A later report of the data were made by Lee and Iliff (1956), but individual measurements were not included.

(7) The recent data from Kansas on newborn premature infants reported by Miller *et al.*, (1961) are the latest data available at this time.

TABLE 1.—*Investigators reporting metabolic measurements on Healthy, Undernourished, and Premature infants, birth to 3 years of age, and pertinent information regarding measurements and infants*

[Measurements made while asleep and after feeding except as noted.]

Laboratory and investigator(s)	Type of apparatus	Results based on—	Description of infants [1]	Comments
			A. Healthy infants	
Carnegie Institution, Boston:				
Benedict and Talbot (1915)	Closed-circuit	Average minimum value from several 10- to 30-minute tests when there was little or no muscular activity and pulse rate was low.	Ninety-two newborn healthy infants under 1 week old. Infants measured when less than 13 hours old, not fed.	Data also given in Harris and Benedict, 1919 (not listed).
Benedict and Talbot (1921)	do	do	Seventy-two infants, 1 week to 2 years old. Some infants below weight for age but otherwise normal from physical examination. About half measured 2 or more times.	Data for some infants reported in other publications, but included once in this report. *See* 1914 report under "Undernourished infants," below.
Cornell University and the University of Rochester,[2] New York:				
Bailey and Murlin (1915)	do	Average, in most cases of 2 consecutive tests (40 to 90 min.).	Five normal infants 6 hours to 12 days old. Measurements on 2 infants repeated at intervals.	Height [3] not reported. Measurements made while infant crying, omitted.
Murlin and Hoobler (1915)	do	Average of 3 or 4 hourly tests in which the infant was sleeping throughout.	Seven healthy infants and one temporarily underweight infant, 2 to 12 months old.	Height [3] not reported. Data on 2 infants omitted as they were "much underweight."
Murlin, Conklin, and Marsh (1925).	do	Average, for most, of 2 to 7 tests (30 to 100 min.); others had 1 test.	Thirty-five normal infants, birth to 14 days old. From parents in good financial circumstances.	Height [3] not reported. Influence of food and crying. Only period designated "basal" used.
Columbia University, New York City:				
Marine, Lowe, and Cipra (1922).	Open-circuit	One 1-hour observation	Two normal infants measured repeatedly from 2- to 5-day intervals for 1 month.	
Benjamin and Weech (1943)	do	One 30- to 90-minute test in which there was little or no activity.	Two healthy male infants, 6 to 15 months old; from poor families.	Longitudinal study. Data on nonwhite infants omitted.
Cornell University Medical College, New York City:				
Levine and Marples (1931)	Closed-circuit	Average of 2 or more hourly observations.	Six well-nourished and 3 moderately undernourished infants, 1 to 12 months old.	Data for some infants reported in other publications, but included once in this report. *See* Levine *et al.* (1928) and Watt *et al.* (1932) under "Undernourished infants," below.
Dann, Kelly, McNamara, and Curtis (1942).	Open-circuit	Average of several 30-minute periods in which there was little or no activity.	Three full-term male infants, 37 to 94 days old.	Study on amino acids. Only "control" periods used. Height [3] not reported.

See footnotes at end of table.

TABLE 1.—*Investigators reporting metabolic measurements on Healthy, Undernourished, and Premature infants, birth to 3 years of age, and pertinent information regarding measurements and infants*—Continued

[Measurements made while asleep and after feeding except as noted.]

Laboratory and investigator(s)	Type of apparatus	Results based on—	Description of infants [1]	Comments
		A. Healthy infants—Continued		
New York State College of Home Economics, Ithaca:				
Clagett and Hathaway (1941)	Open-circuit	One 30-minute (or longer) test in which there was little or no activity.	Three pairs of twins and 2 unrelated boys, 4 to 15 months old. Considered normal and well-developed for size.	Measurements repeated at approximately monthly intervals.
Child Research Council, Denver:				
Lee (1952)	do	One 30-minute test in which there was no gross movement.	Fifty-six children from private homes in Denver and vicinity, 1 to 38 months old.	Measurements repeated at about 3-month intervals.
		B. Undernourished infants		
Carnegie Institution and Massachusetts General Hospital, Boston:				
Benedict and Talbot (1914a, 1914b).	Closed-circuit	Average minimum value from several 10- to 30-minute tests when there was little or no muscular activity, and pulse rate was low.	Underweight infants in the subnormal temperature stage of infantile atrophy or in the repair stage with normal temperature.	Measurements on 40 infants reported in addition to data included in the 1921 report under "Healthy infants," above.
Talbot (1921)	do	do	Seventeen infants with severe malnutrition, 2 to 14 months old.	Height [3] not reported.
Cornell University Medical College, New York City:				
Levine, Wilson, and Gottschall (1928a).	do	Average of 2 or more hourly observations.	Five marantic infants markedly emaciated.	Data on 3 healthy infants included in Levine and Marples (1931), above.
Watt, Weymuller, and Levine (1932).	do	do	Six infants moderately undernourished or markedly emaciated.	Study concerned with calorigenic action of thyroid extracts; only control observations used. Data on well-nourished infants included in Levine and Marples (1931) above.

	C. Premature infants			
Massachusetts General Hospital, Boston:				
Talbot, Sisson, Moriarty, and Dalrymple (1923).	Closed-circuit	One test, ranging in length from 50 to 180 minutes.	Nineteen infants at least 4 to 10 weeks premature; weighed less than 2.5 kilograms at birth.	Some infants measured at one age; some at several ages, and one at repeated intervals for 3 months.
Cornell University and the University of Rochester,[2] New York:				
Marsh and Murlin (1925)	do	Average of 2 tests for about half of infants; one test for others. Tests were from 30 to 70 minutes long.	Fifteen premature and undersized infants 3 to 14 days old. Data on infants weighing more than 2.5 kilograms omitted.	Height [3] not reported. Tests repeated at an interval of several days.
Cornell University Medical College, New York City:				
Gordon and Levine (1936)	do	Average of 2 or more hourly observations.	Twenty-one infants, 2 to 67 days old.	Tests repeated at intervals of 10 days or longer on most infants.
Gordon, Levine, Deamer, and McNamara (1940).	Open-circuit	Average of several 30-minute periods in which there was little or no activity.	Seven infants, 10 to 65 days old	Data on nonwhite infants omitted.
Dann, Kelly, McNamara, and Curtis (1942).	do	do	Ten male infants, 11 to 78 days old.	Height [3] not reported. Study on amino acids; only "control" periods used.
Day (1943)	do	do	Twenty-two male infants, 4 to 35 days old; birth weights less than 2.5 kilograms.	Height [3] not reported. Tests omitted in which infant was asleep.
University of Kansas Medical Center, Kansas City:				
Miller, Behrle, Hagar, and Denison (1961).	Closed circuit (with face mask).	Average of duplicate 5-minute tests.	Eight "healthy premature" infants, 15 to 47 hours old. Sex not reported.	Study concerned with effect of high humidity. Measurements made at high relative humidity (82–94%) used for this report. When more than one measurement reported (15 to 24 hours apart), the average value of these was used.

[1] All white infants. Any data on nonwhite infants were omitted from this report if they were described as such. However, it is recognized that some observations on nonwhites may have been included because a complete description of the infants was not always given.

[2] The work of Murlin and associates is grouped together, although the measurements were made at two laboratories—the Physiological Laboratory of Cornell University Medical College, New York City, and the University of Rochester, New York.

[3] No distinction between height and length is made in this report. Height is used to refer either to standing height or reclining length.

II. Weight-For-Height Classification

In order to differentiate between infants of the same height [1] but of different weight, a means of classifying the infants according to weight for height was established. This enabled us to use classifications similar to those derived for children 2 years of age and older in the previous analysis (Sargent, 1961).

The height-weight data from the Iowa Child Welfare Research Station (1931) were chosen as being the most comparable to the Stuart-Meredith (1946) Standards based on Iowa City children. These Standards were used previously for establishing the weight-for-height classification of children 2 years of age to puberty. Average monthly weights and heights from 2,303 infants, 1 to 36 months of age, are shown plotted on a semilogarithmic grid in figure 1. The slope of the line drawn through these data indicates that weight for height increases at a much faster rate from age 1 month to about 10 months (72 centimeters height) than for ages 11 months and older. This means that in relation to height, infants (on the average) accumulate weight more rapidly before than after 10 months of age. The slightly low points at 1 month, no doubt, reflect the loss of weight normally occurring during the first week after birth.

The data points after 10 months are generally lower, but fall close to the average line previously used to represent the relationship between weight and height for children 2 years of age to puberty (*see* Sargent, 1961). These lower values may be explained, in part, by the difference between weights taken without clothing (1931) and in underclothes (1946). Therefore, the weight-for-height classifications previously established are considered applicable to infants 11 months of age and older.

The change in the rate of increase in weight per unit increase in height at about 10 months of age, or 72 centimeters height, is in line with that observed by others. Brody (1927, 1945), using data by Woodbury (1921) and logarithmic grids, showed a break in the weight-for-height relationship at about 70 centimeters height. This break was reported to be at 10 months of age in the 1927 publication but at 1 year in the 1945 publication and was attributed to the "end of the exclusive dependence on milk."

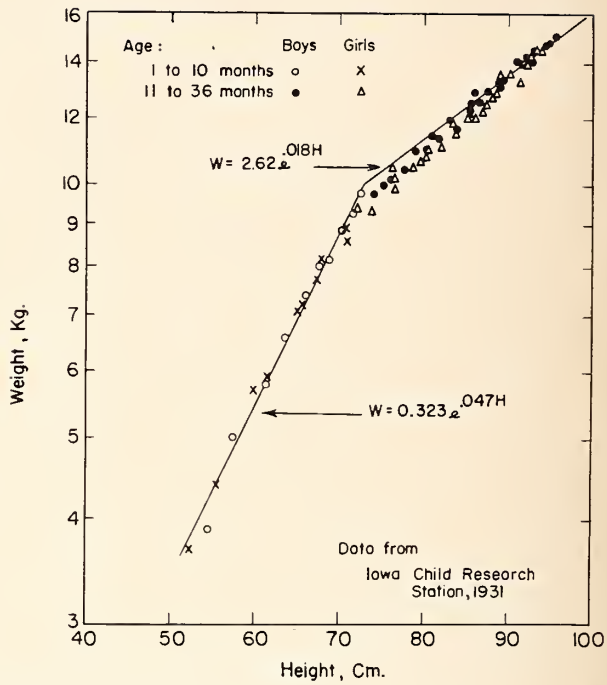

Figure 1.—Iowa infants, 1 to 36 months of age: Height-weight data plotted on semilogarithmic paper.

Measurements were made without clothes. Data points represent monthly averages; each an average of 8 to 62 measurements. The equation shown for infants 10 months of age and younger was fitted to the data by the method of least squares. The equation shown for infants 10 to 36 months of age was derived for children 2 years of age to puberty. (*See* Sargent, 1961.)

Adams and Poulton (1937) confirmed the inflection at 1 year of age, or 74 centimeters height, described by Brody (1927), and explained the break as a difference in increased activity between the two age periods: "A possible explanation of the kink is the exercise taken by the child when she begins at first to crawl and later to run about; these activities burn up fat and consequently the luxus consumption associated with fat storage and over-nutrition of babyhood disappear."

Bayley and Davis (1935) reported that infants ceased to increase in stockiness and started to grow more slender at 11 months. This conclusion was reached from results on a seriatim growth study of 46 to 69 infants, 1 to 36 months of age.

[1] It is recognized that *length* is the measurement made for infants until 12 or 18 months (or until the child can stand erect by himself), and sometimes longer—up to 3 years. However, no distinction between height and length will be made in this discussion—*height* will be used to refer either to standing height or reclining length.

From several body-build indices, they concluded that the weight:length² index was "the most valid measure of relative chubbiness, or lateral-linear tendencies in build." The age curve of the weight:length² index shows (for the average) a rapidly increasing trend during the first 11 months and a slowly decreasing trend after this age.

Stuart and Sobel (1946), and more recently Garn (1956), reported that from measurements made at 3-month intervals, the thickness of subcutaneous tissue in the leg increases rapidly during the first 9 months of infancy, then decreases. Garn reported that some infants began to lose fat at 6 months, but the majority accumulated fat up to 9 months and thereafter began to lose it. Furthermore, Garn pointed out that milk is a high-fat food and that "the age at which infants begin to lose fat is the age at which milk begins to play a decreasing role as the major source of calories."

In this connection, Watson and Lowrey (1954) stated that the breast-fed infant obtains nearly 50 percent of his caloric intake from fat but that after weaning "not over 35 percent of the total caloric intake should be in the form of fat."

Stuart and Stevenson (1959) described the infancy period, 1 month to 1 year, as a period of rapid growth; the "transition" period or late infancy, 1 to 2 years, as a period of decelerating growth; and the "preschool" period, 2 to 6 years, as a period of slow growth.

The difference in body size for age of the children measured may explain, in part, the slight discrepancy as to the average age at which the change in body-build occurs. However, the earlier age reported by Stuart and Sobel (1946) and by Garn (1956) in this connection is attributed to the 3-month interval between measurements. Therefore, the change cannot be said to occur at 9 months but between 9 and 12 months. For the average curve, we have made this break *after* 10 months of age, appreciating, of course, the differences in individual children.

On the basis of evidence from the literature reported herein, the logical explanation of the "break" in the relationship between the average weight and height is that the infant ceases to accumulate fat at about 10 months of age. This change in body-build is, no doubt, associated with an increase in energy expenditure due to an increase in muscular activity as motor development progresses, and possibly, with changes in diet as the weight gain becomes less and the body fat stored during early infancy is utilized.

The slope of the line drawn through the data points representing weight for height of infants up to 10 months of age is 0.047 (figure 1). This means that for each centimeter increase in height, weight increases at the constant rate of 4.7 percent. For infants older than 10 months, the increase in weight is 1.8 percent per centimeter increase in height. Thus, for infants younger than 10 months of age, weight will be doubled with an increase in height of 14.7 centimeters; for infants older than 10 months of age, weight will be doubled with an increase in height of 38.5 centimeters.

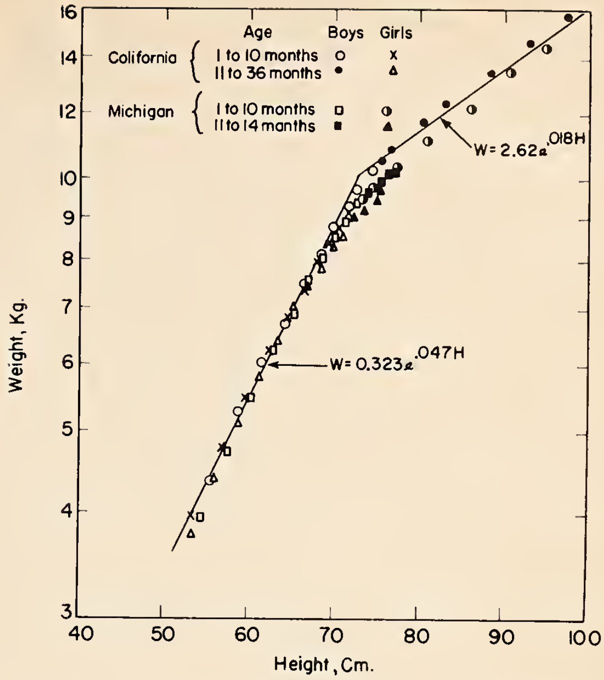

FIGURE 2.—CALIFORNIA AND MICHIGAN INFANTS: Height-weight data plotted on semilogarithmic paper and shown in relation to the regression line derived from data on Iowa infants.

Measurements were made without clothes. Data points shown for California infants (from Bayley and Davis, 1935) represent averages for 31 boys and 30 girls measured repeatedly at monthly intervals up to 12 months, at 15 and 18 months, and thereafter, at 6-month intervals up to 36 months of age. Data points for Michigan infants (from Raiford, 1938) represent averages for from 134 to 281 girls or boys for each month from 1 to 14 months of age.

Height-weight data from Bayley and Davis (1935) for California infants and from Raiford (1938) for Michigan children, show in figure 2 that the relationship between weight and height is similar to that of the Iowa data—the rate changes at about the same age (10 months) and thereafter tends to parallel the average line derived from the Stuart-Meredith data.

Weight-for-height classifications similar to those established for older children (Sargent, 1961) were set up for infants up to and including 10 months of age. The equation,

$$\text{Weight} = 0.323e^{0.047(\text{height})},$$

obtained from the Iowa data was used for the line of average relationship (*see* figure 1). These classifications are shown in figure 3.

As in the previous analysis, the difference between the sexes was so slight that no distinction was made in the weight-for-height classification. However, at 10 months of age boys are, on the

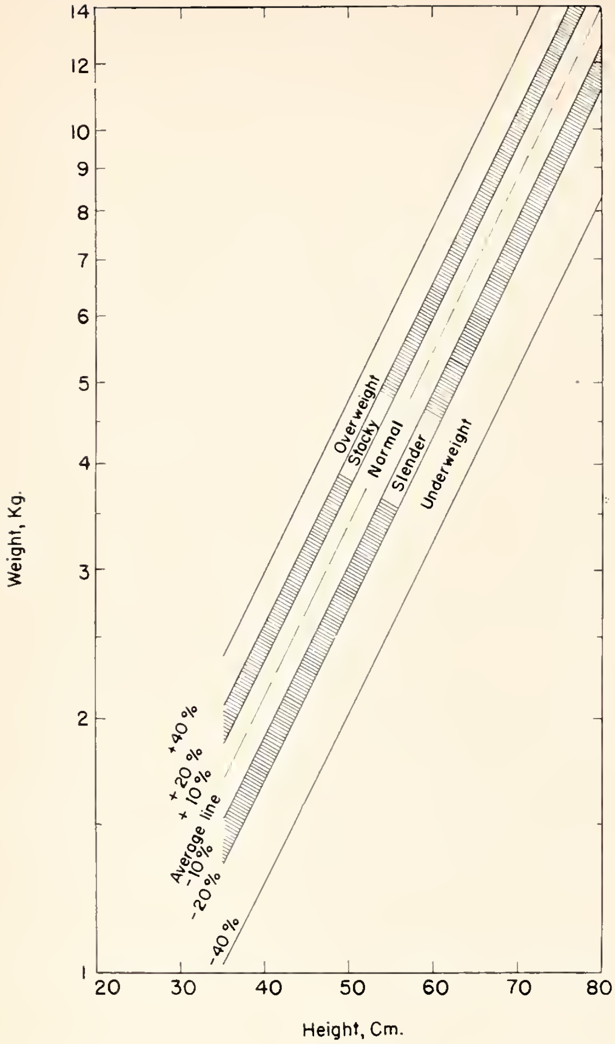

FIGURE 3.—INFANTS 1 TO 10 MONTHS OF AGE, INCLUSIVE: Weight-for-height classifications.

Values used to establish the average line were as follows: For 50 cm., 3.40 kg.; for 60 cm., 5.44 kg.; and for 70 cm., 8.70 kg.

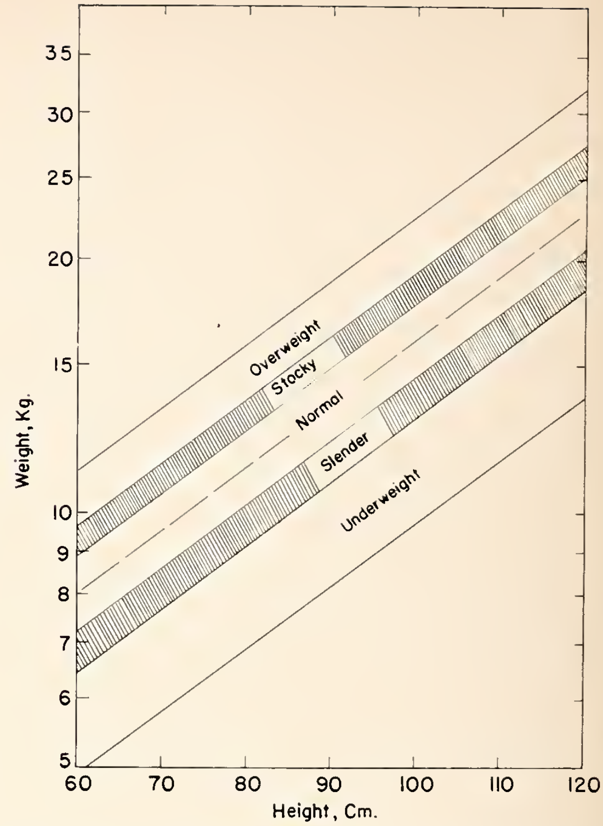

FIGURE 4.—INFANTS 11 MONTHS OF AGE AND OLDER (BETWEEN 60 AND 120 CENTIMETERS IN HEIGHT): Weight-for-height classifications.

Values used to establish the average line were as follows: For 70 cm., 9.24 kg.; for 90 cm., 13.24 kg.; and for 110 cm., 19.00 kg.

average, 2 centimeters taller and between 0.5 to 1.0 kilogram heavier than girls.

Since the classifications previously derived (*see* Sargent, 1961) for the older children are applicable to infants older than 10 months, a portion of the chart showing these classifications is reproduced in figure 4.

III. Correlation of Basal Metabolism With Weight

In the preceding publication, linear equations were derived for the regression of basal heat production on weight for each of the three physiological age intervals—Preschool, School Age to Puberty, and Postpubertal. Likewise, linear equations may be derived to represent heat production in full-term infants, provided that the data are separated into the following three age intervals: [2] Newborn (birth to 6 days, inclusive), 1 week to 10 months, and 11 months and older.

As in the previous analysis, the "breaks" (at 1 week of age and at 10 months of age) correspond to physiological changes. Since longitudinal data were not available for each infant for a sufficient length of time, chronological age had to be used for separating the data into age intervals. The ages given were based on the average chronological age at which these physiological changes occurred for the data presented herein. However, it is appreciated that there are great differences among infants in the age at which these changes occur.

Talbot *et al.* (1923) reported that "metabolism during the first days of life, in the premature as well as in normal infants, differs from their metabolism after they have become adapted to their surroundings." Thus, the Newborn age interval is considered an adjustment period for adaptation of the infant from an intrauterine to an extra-uterine environment. The end of this adjustment period probably coincides with the age at which the Newborn infant stops losing weight and begins to gain. From these data a rise in heat production began, on the average, with the seventh day, whereas Stuart and Stevenson (1959) reported that weight gain began "usually by the fifth day." Table 2 indicates that heat production of Newborn infants (under 1 week old) is, on the average, 0.8 Calorie per hour lower than that of infants 7 days to 1 month old and within the same weight interval. However, the difference appears to increase with increasing weight.

Marine *et al.* (1922) pointed out that the age curve for heat production shows that "an increase begins shortly after birth and reaches its maximum intensity ordinarily between the tenth and twelfth months of extra-uterine life."

That there is a break in the curves relating heat production to weight at about 10 months of age is illustrated in figures 5 and 6. The slope of the lines for infants older than 10 months are less steep than those for infants under 10 months of age. This break at 10 months of age coincides with the break found in the curve representing the relationship between weight and height discussed in the preceding section. Adams and Poulton (1937) also reported that a break occurred in the basal metabolism (represented by the relation of log CO_2 to log weight) of infants which corresponded to the change in the relation of log weight to log height.

It is generally agreed that heat production is the same for boys and girls during infancy (Levine and Marples, 1931; Clagett and Hathaway, 1941; Karlberg, 1952). However, there are differences of opinion as to the age at which a sex differentiation in heat production begins. Benedict and Talbot (1921) reported that there is "little or no sex differentiation below the weight of 11 kilograms"; Lee and Iliff (1956) concluded from their recent investigations that the "difference between the energy production of boys and girls up to 3 years of age could be attributed to differences between the sexes in body size for age and body weight for height"; and Watson and Lowrey (1954) reported that "Until age 8 (years) there is only a slight difference between the sexes." (*See* also Harris and Benedict, 1919; Adams and Poulton, 1937; Brody, 1945.)

Figures 5 and 6 indicate that a sex differentiation in heat production begins about 10 months of age (corresponds to a weight of between 9 and 10 kilograms). During the age interval 2 to 10 months, the curves relating heat production to weight are approximately the same for boys and for girls. But after 10 months of age, the curves for the boys (figure 5) show a decided increase to a higher elevation before the lines flatten out; whereas, the curves for the girls (figure 6) flatten out at about the time of the break and continue at approximately the same elevation.

Linear regression equations relating heat production to weight for boys and for girls were calculated (if sufficient measurements were available) for the following:

A. Three groups of infants, separated according to their nutritional state or physiological development (discussed in Section I): Healthy infants, Undernourished infants, and Premature infants.

B. Three age intervals for full-term infants: Birth to 6 days (Newborn), 1 week to 10 months,

[2] The age intervals for premature infants (to be discussed in part C) are Newborn (birth to 10 days, inclusive) and 11 days and older. Data were not available for a third age interval.

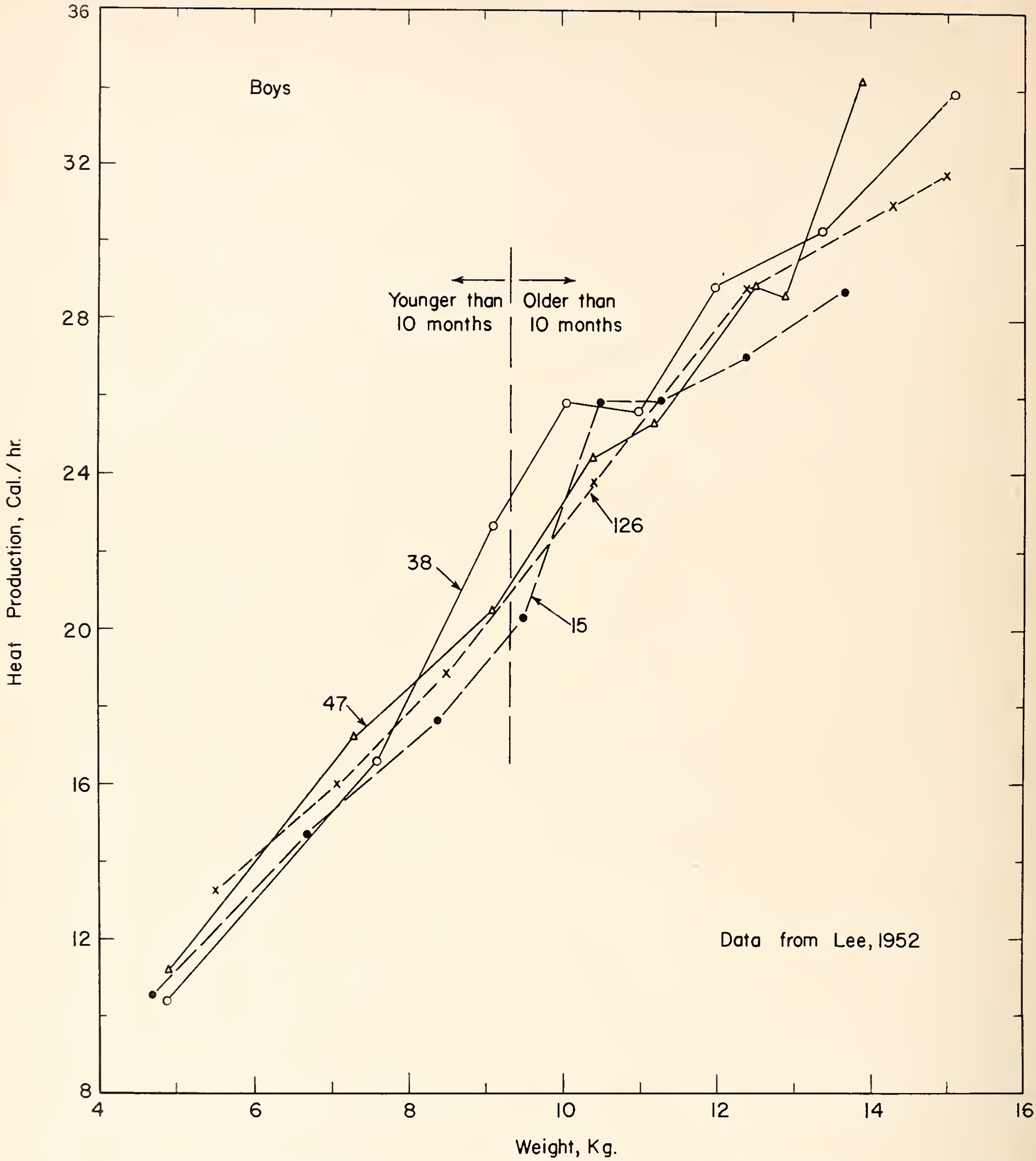

FIGURE 5.—BOYS: Relationship between basal heat production and weight.

The data points are connected for each of 4 infants and represent measurements made at intervals of several months between 2 and 36 months of age.

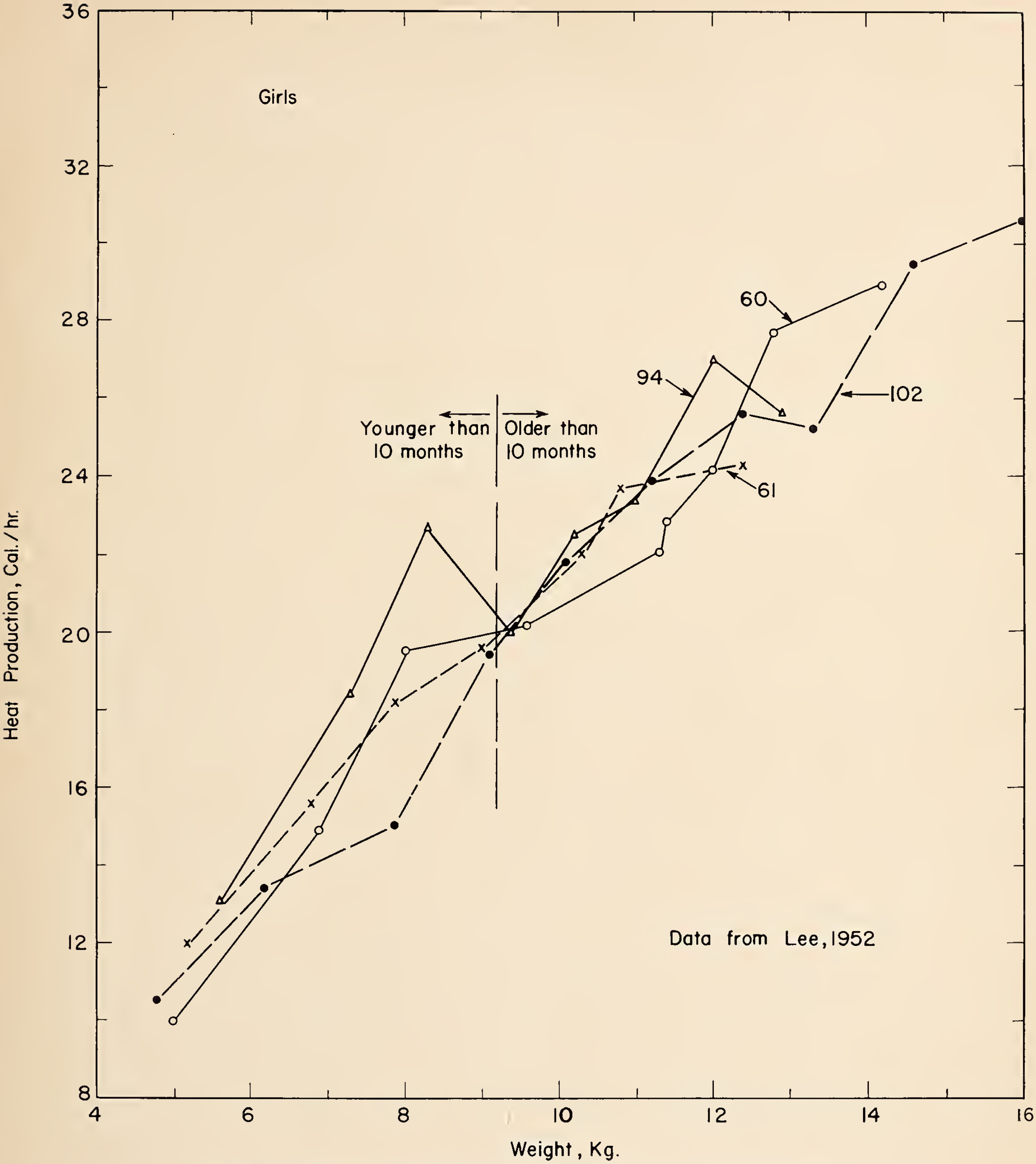

FIGURE 6.—GIRLS: Relationship between basal heat production and weight.
The data points are connected for each of 4 infants and represent measurements made at intervals of several months between 2 and 38 months of age.

Table 2.—*Heat production averaged by weight intervals for Newborn infants (under 1 week old) and for infants 7 days to 1 month old*

[All infants fed; not classified according to weight-for-height.]

Weight interval, kilograms	Infants under 1 week old			Infants 7 days to 1 month old		
	Measurements	Weight	Heat production	Measurements	Weight	Heat production
	Benedict and Talbot (1915; 1921)					
	Number	*Kg.*	*Cal./hr.*	*Number*	*Kg.*	*Cal./hr.*
2.60–2.79	6	2. 71	5. 51	1	2. 68	5. 79
2.80–2.99	4	2. 88	5. 43	0		
3.00–3.19	5	3. 11	5. 72	0		
3.20–3.39	9	3. 31	6. 03	1	3. 38	6. 79
3.40–3.59	12	3. 50	6. 36	3	3. 51	8. 15
3.60–3.79	9	3. 67	6. 64	2	3. 68	7. 40
3.80–3.99	4	3. 90	6. 83	6	3. 87	8. 04
4.00–4.19	3	4. 08	7. 28	0		
4.20–4.39	2	4. 32	7. 62	1	4. 20	8. 29
4.40–4.59	1	4. 52	7. 83	2	4. 48	8. 10
	Bailey and Murlin (1915); Murlin, Conklin, and Marsh (1925)					
2.60–2.79	3	2. 77	5. 63	0		
2.80–2.99	4	2. 90	5. 64	1	2. 86	6. 15
3.00–3.19	4	3. 12	6. 44	3	3. 05	7. 10
3.20–3.39	3	3. 29	6. 98	1	3. 26	8. 23
3.40–3.59	7	3. 50	6. 51	3	3. 45	6. 50
3.60–3.79	1	3. 73	6. 94	3	3. 69	7. 94
3.80–3.99	4	3. 87	7. 23	2	3. 92	8. 06
4.00–4.19	0			1	4. 05	6. 72
4.20–4.39	1	4. 27	7. 10	1	4. 29	9. 04
4.40–4.59	2	4. 42	8. 44	1	4. 40	8. 14
	Marine, Lowe, and Cipra (1922)					
2.80–2.99	2	2. 92	5. 52	2	2. 87	7. 11
3.00–3.19	2	3. 08	6. 28	4	3. 12	6. 94
3.20–3.39				4	3. 31	7. 73

and 11 to 38 months. The Undernourished infants: Primarily within the second age interval (1 week to 10 months). Two age intervals for Premature infants: Birth to 10 days (Newborn), and 11 days and older (data did not extend beyond age 3 months).

C. Five weight-for-height classifications (discussed in Section II): Underweight, Slender, Normal, Stocky, and Overweight.

A. HEALTHY INFANTS

The number of basal metabolic measurements on Healthy (full-term) infants available for this analysis are given in table 3 for each of the three age intervals. Since the data for infants within the Stocky, Overweight, and Underweight weight-for-height classifications were sparse, they are excluded from this table and only the measurements for Normal and Slender classifications given.

Figure 7 presents the scatter diagrams for the data on Newborn infants (under 1 week old). Results of covariance analysis (*see* appendix, table 11) indicated that the heat production was similar for Newborn boys and girls; therefore, the data for the sexes were combined for this age interval. However, separate equations were derived for infants that were fed before the test and for infants not fed—measured within 13 hours after birth. These equations were of similar slope, but the elevation of the regression line was from 12 to 15 percent lower for the infants not fed than for the infants fed before the tests. This difference was statistically significant (*see* appendix, table 12). These results agree with Talbot's (1925) conclusions that the stimulating effect of food "in new-born infants is approximately 14 percent, while in later infancy and childhood it varies within wider limits of 8 to 15 percent."

TABLE 3.—*Basal metabolic measurements*[1] *analyzed on Healthy infants within the Normal and Slender weight-for-height classifications*[2]

[Measurements made while asleep and after feeding unless otherwise indicated.]

Investigator(s)	Weight-for-height classification	Age interval: Under 1 week (boys and girls)	Age interval: 1 week to 10 months (boys and girls)	Age interval: 11 to 38 months: Boys	Age interval: 11 to 38 months: Girls	Total
		Number	*Number*	*Number*	*Number*	*Number*
Benedict and Talbot (1915, 1921)	Normal	[3] 64	79	9	8	208
	Slender	[3] 21	18	4	5	
Bailey and Murlin (1915)	(4)	6	3	----	----	54
Murlin and Hoobler (1915)	(4)	0	7	1	0	
Murlin, Conklin, and Marsh (1925)	(4)	24	13	----	----	
Levine and Marples (1931)	Normal	0	5	1	0	13
	Slender	0	3	0	0	
Dann, Kelly, McNamara, and Curtis (1942)	(4)	0	4	0	0	
Marine, Lowe, and Cipra (1922)	(4)	4	17	0	0	33
Benjamin and Weech (1943)	Normal	0	5	0	0	
	Slender	0	3	4	0	
Clagett and Hathaway (1941)	Normal	0	18	0	0	49
	Slender	0	20	1	10	
Lee (1952)	Normal	0	109	61	69	299
	Slender	0	21	17	22	
Total		119	325	98	114	656

[1] Measurement is used herein to indicate one test, or an average of several tests, made at a specified age. Tests repeated on the same infant at a later age were considered another measurement. Measurements on the same infant sometimes were made within a day or two; for infants under 1 month of age, measurements were used as reported but for infants older than 1 month, they were averaged by months.

[2] Data on infants within the other weight-for-height classifications were excluded as there were too few for analysis.

[3] This group consists of 39 fed and 25 not-fed infants for the Normal classification and 14 fed and 7 not-fed infants for the Slender classification. Infants not fed were measured within 13 hours after birth.

[4] Height not reported; therefore, classification could not be determined.

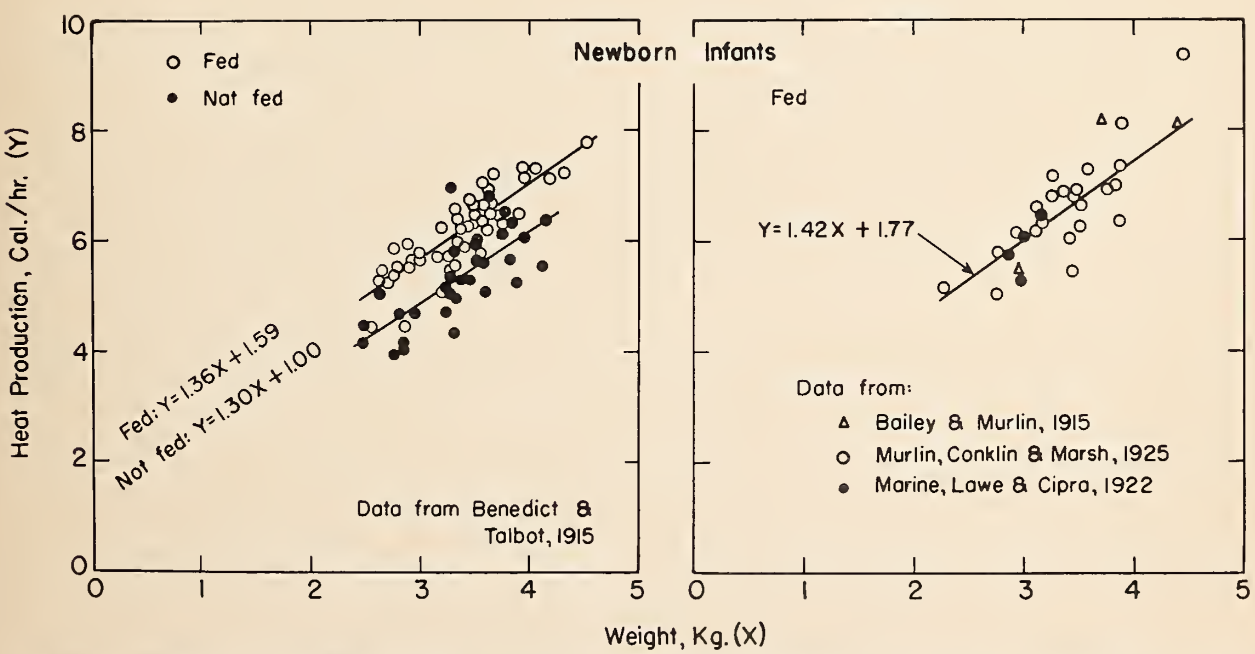

FIGURE 7.—NEWBORN (FULL-TERM) INFANTS: Scatter diagrams and regression lines showing the relationship between basal heat production and weight.

Table 4.—Newborn infants: *Regression equations, standard errors of estimate, and correlation coefficients for the linear relationship between heat production and weight*

[Data for boys and girls combined.]

Investigator(s)	Weight-for-height classification	Age range	Weight range	Infants	Measurements	Regression equation Y=Calories/hr. X=Weight, kg.	Correlation coefficient [1]	Standard error of estimate
		Fed						
		Days	*Kg.*	*Number*	*Number*			*Cal./hr.*
Benedict and Talbot (1915).	Normal	½–6	2. 8–4. 5	39	39	Y=1. 31X+1. 77	0. 80	0. 35
	Slender	½–6	2. 6–3. 5	14	14	Y=1. 45X+1. 32	. 67	. 48
	Normal and Slender.	½–6	2. 6–4. 5	53	53	Y=1. 36X+1. 59	. 85	. 38
Bailey and Murlin (1915)	[2]	3–6	2. 8–4. 4	3	6	Y=1. 42X+1. 77	. 80	. 57
Murlin, Conklin, and Marsh (1925).	[2]	2–6	2. 3–4. 4	24	24			
Marine, Lowe, and Cipra (1922).	[2]	2–6	2. 9–3. 2	2	4	[3]		
		Not fed						
		Hours						
Benedict and Talbot (1915).	Normal	2–13	2. 8–4. 1	25	25	Y=1. 30X+1. 00	0. 72	0. 57
	Slender	2–13	2. 5–3. 6	7	7			

[1] All significant at the 1-percent level.
[2] Height not reported; therefore, classification could not be determined.
[3] Number of measurements too small for deriving a separate equation.

The regression lines fitted to the data of Benedict and Talbot (1915) for Newborn infants within the Normal and the Slender weight-for-height classifications were similar (*see* table 4), and when tested statistically, were not significantly different (*see* appendix, table 13). For this reason, it was deemed appropriate to combine the data for these classifications, and also to compare the regression line obtained from the combined data for the Normal and Slender classifications with those from Murlin and associates (1915, 1925) for which the weight-for-height classification could not be determined. (The assumption is made that data on Stocky or Underweight infants were not included in the Murlin report.)

Although the slopes of the regression lines derived for Newborn infants from the data of Benedict and Talbot (1915) and the data for Murlin and associates (1915; 1925) were similar, the elevation of the regression line for the Murlin data was about 6 percent higher. This difference was statistically significant (*see* appendix, table 14). The selection of test results by these investigators could well be the explanation for this difference. Benedict and Talbot selected tests in which heat production was at a minimum, whereas Murlin and associates apparently made no selection (*see* table 1). The slightly lower standard error of estimate for the data from Benedict and Talbot is also indicative of a selection of tests. The few data by Marine *et al.* (1922) are comparable to those of Murlin and associates (figure 7).

Scatter diagrams showing the relationship between heat production and weight for infants older than 1 week and within the *Normal weight-for-height classification* are shown in figure 8 for Massachusetts infants (data from Benedict and Talbot, 1921) and in figure 9 for Colorado infants (data from Lee, 1952).

For the 1-week to 10-month age interval the regression lines for boys and girls were similar. Since the results from statistical tests confirmed this (*see* appendix, table 11), the data for boys and for girls were combined and the resulting statistical measures presented in table 5. The results from statistical tests (*see* appendix, table 14) also indicated that the equations derived from the Benedict-Talbot and the Lee data were similar. Therefore, these data were combined (including the data from other investigators having data insufficient for separate analysis) and one equation was derived to represent heat production as a function of weight for these infants (table 5).

For the 11- to 38-month age interval the regression line for boys was higher than that for the girls (figure 9). This difference in elevation was statistically significant at the 5-percent level, although the slopes of the regression lines (rate of increase in heat production per unit increase in weight) were approximately the same for both boys and girls (*see* appendix, table 11). These results confirm the tentative conclusion drawn

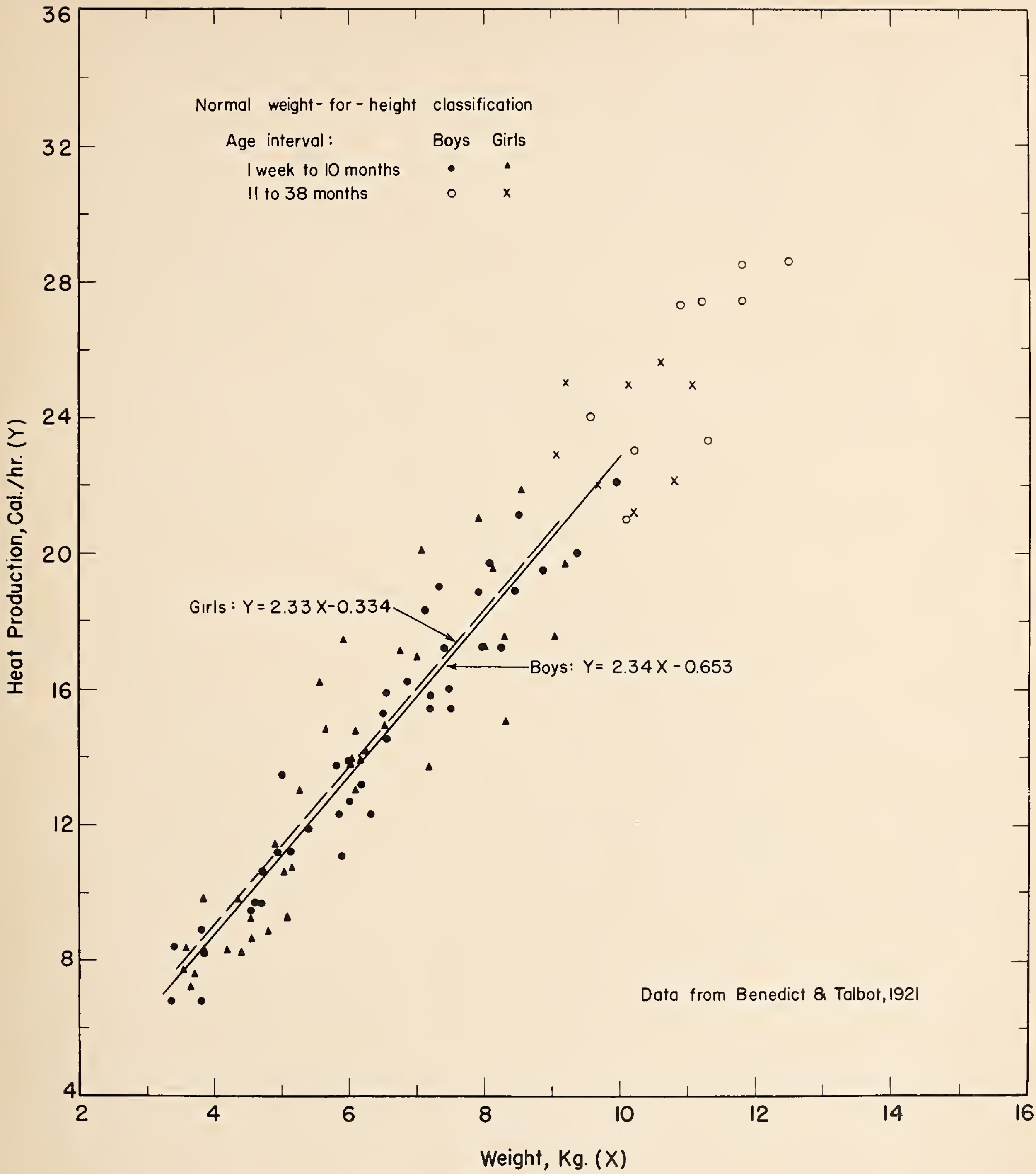

FIGURE 8.—MASSACHUSETTS INFANTS WITHIN THE NORMAL WEIGHT-FOR-HEIGHT CLASSIFICATION: Scatter diagram and regression lines showing the relationship between basal heat production and weight.

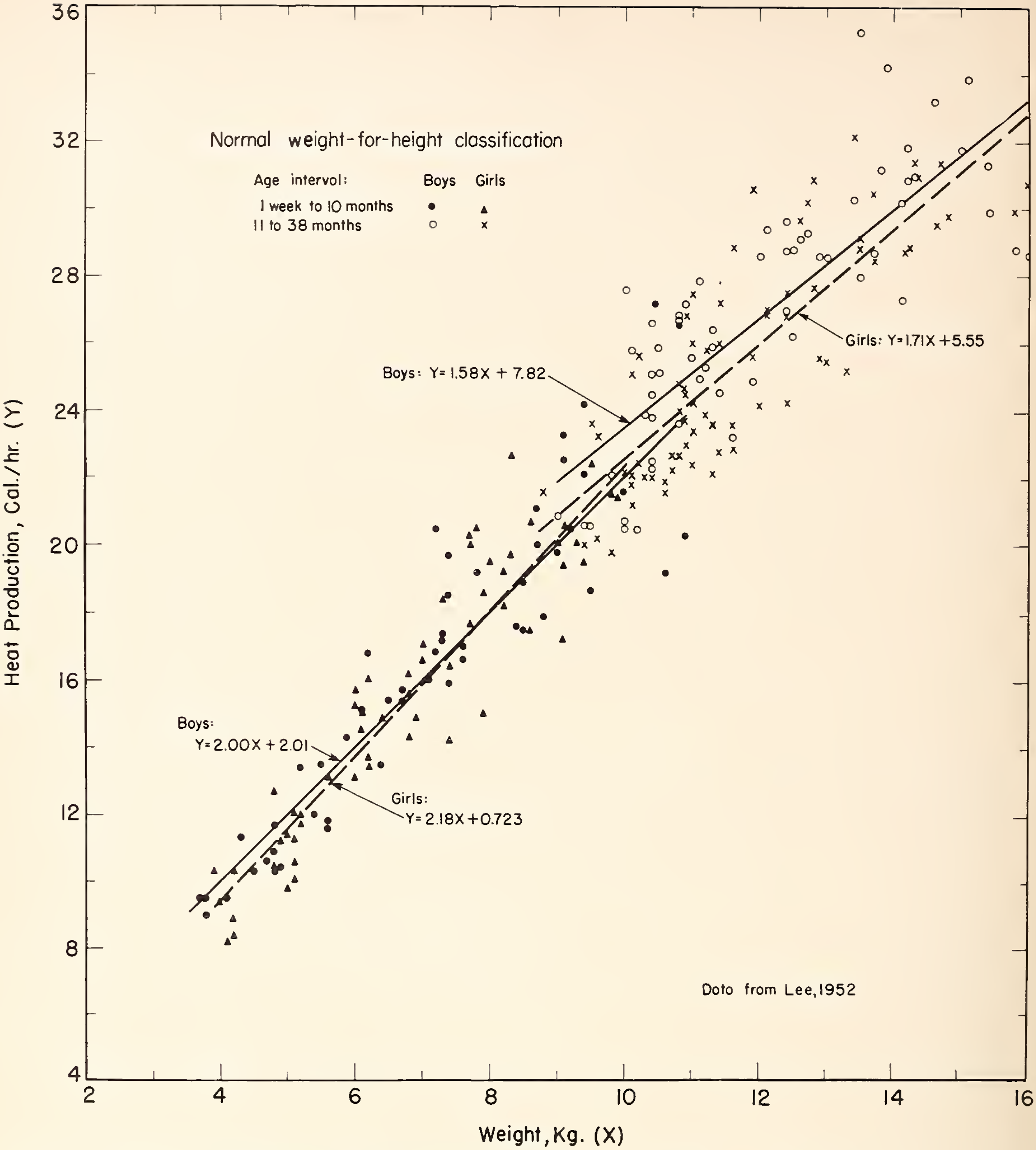

FIGURE 9.—COLORADO INFANTS WITHIN THE NORMAL WEIGHT-FOR-HEIGHT CLASSIFICATION: Scatter diagram and regression lines showing the relationship between basal heat production and weight.

from figures 5 and 6 that a sex differentiation in heat production began at about 10 months of age. The statistical measures for boys and for girls derived from the data of Lee (1952) are given in table 5. Data from other investigators[3] for this age group were insufficient for separate analysis. On the basis of the younger age group, we have assumed that the data from all investigators are comparable; therefore, all the available data were combined to derive one equation for each sex to represent heat production as a function of weight for these infants (table 5).

[3] Although Benedict and Talbot (1921) reported measurements on children over 2 years of age, these data are not comparable to data obtained on younger infants as explained at the beginning of this report.

TABLE 5.—NORMAL WEIGHT-FOR-HEIGHT CLASSIFICATION: *Regression equations, standard errors of estimate, and correlation coefficients for the linear relationship between heat production and weight*

Investigator(s)	Age range	Weight range	Infants	Measurements	Regression equation Y=Calories/hr. X=Weight, kg.	Correlation coefficient [1]	Standard error of estimate
	Boys and girls: 1 week to 10 months						
	Months	*Kg.*	*Number*	*Number*			*Cal./hr.*
Benedict and Talbot (1921)	¼–10	3. 4– 9. 9	58	79	Y=2. 33X−0. 440	0. 93	1. 55
Levine and Marples (1931)	1– 8	3. 6– 6. 4	5	5	[2]		
Clagett and Hathaway (1941)	3–10	5. 3– 9. 4	4	18	[2]		
Benjamin and Weech (1943)	6– 8	6. 9– 7. 8	2	5	[2]		
Lee (1952)	1–10	3. 7–10. 9	49	109	Y=2. 09X+1. 36	. 93	1. 52
Above data combined	¼–10	3. 4–10. 9	118	216	Y=2. 18X+0. 737	. 92	1. 62
	Boys: 11 to 38 months						
Benedict and Talbot (1921)	11–24	9. 5–12. 5	5	9	[2]		
Levine and Marples (1931)	12	12. 0	1	1	[2]		
Lee (1952)	11–38	9. 0–16. 1	18	61	Y=1. 58X+7. 82	0. 79	2. 22
Above data combined	11–38	9. 0–16. 1	24	71	Y=1. 59X+7. 74	. 79	2. 15
	Girls: 11 to 38 months						
Benedict and Talbot (1921)	11–21	9. 1–11. 1	6	8	[2]		
Lee (1952)	11–38	8. 8–16. 1	19	69	Y=1. 71X+5. 55	0. 83	1. 91
Above data combined	11–38	8. 8–16. 1	25	77	Y=1. 63X+6. 48	. 82	1. 92

[1] All significant at the 1-percent level.
[2] Number of measurements on a few infants too small for deriving a separate equation but are included in the equations for the combined data.

Scatter diagrams for the data on infants within the *Slender weight-for-height classification* are shown in figures 10 and 11.

For the 1-week to 10-month age interval the data for Slender boys and girls were combined, since sufficient measurements were not available for deriving separate equations for each sex, and since the results obtained on infants within the Normal classification indicated that the regression lines for the sexes were similar. Separate equations for the Benedict-Talbot and Lee data are given in table 6, as well as the equation derived from the combination of all data, since the regression lines were similar (*see* appendix, table 14).

For the 11- to 38-month age interval the regression line for the Slender girls is slightly (but not significantly) higher than the line for Slender boys (figure 11). These results, especially for the Slender boys, probably do not represent the true relationship for several reasons: (1) The sample consisted only of four or five measurements on three boys and one or two measurements on two boys; and (2) for the Normal weight-for-height classification, the slope of the regression line for the older age interval was relatively flatter than for the younger age interval, whereas for the Slender classification, the opposite was true.

A comparison of the regression lines for infants within the Normal and Slender weight-for-height classifications indicates that the slopes of the regression lines are similar, but the elevation of the lines for the Slender are significantly higher than those for the Normal classification within the age interval 1 week to 10 months (*see* appendix, table 13). For the older age interval, the elevation of the regression line for the Slender girls was significantly higher than the line for the Normal girls, but for the boys, no significant difference was found between these classifications (*see* appendix, table 13). However, as mentioned previously, the line for the Slender boys is not considered representative.

The data for unclassified infants within the 1-week to 10-month age interval (*see* table 3) were not comparable to the other data, since the difference between the Normal and Slender classifications was statistically significant. Neither were the data suitable to analyze separately because of the narrow weight range (with three exceptions, all the infants weighed less than 4.7 kilograms); furthermore, the 17 measurements from Marine *et al.* (1922) were obtained on only two infants.

Figure 12 shows that individual differences in heat production may be great even in twins raised under similar conditions. Paul had an extremely high heat production as compared with his fraternal twin Patricia, whose heat production was within plus and minus one standard error of esti-

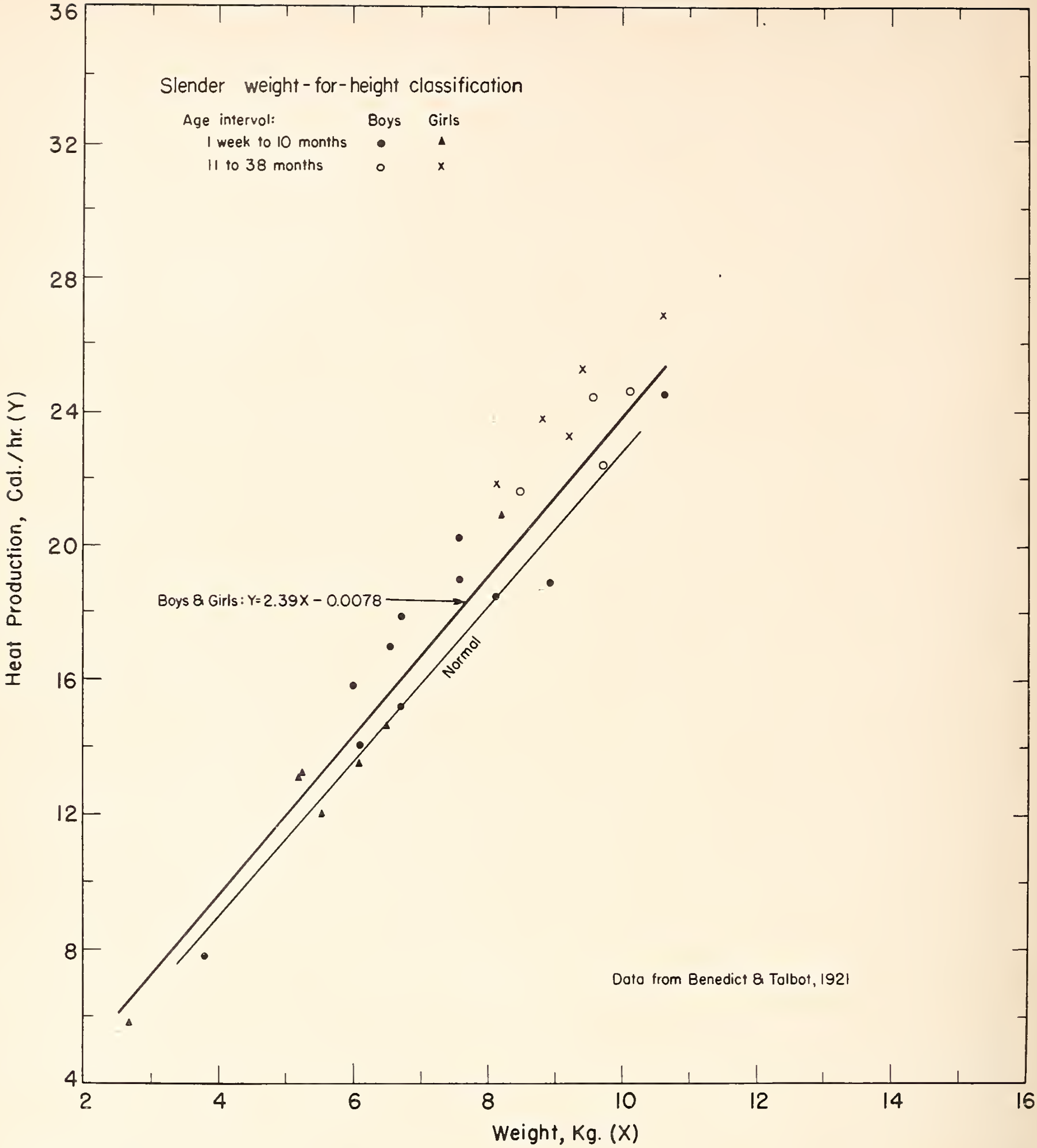

FIGURE 10.—MASSACHUSETTS INFANTS WITHIN THE SLENDER WEIGHT-FOR-HEIGHT CLASSIFICATION: Scatter diagram and regression line showing the relationship between basal heat production and weight.

The regression line for Normal infants, 1 week to 10 months of age, is shown for comparative purposes.

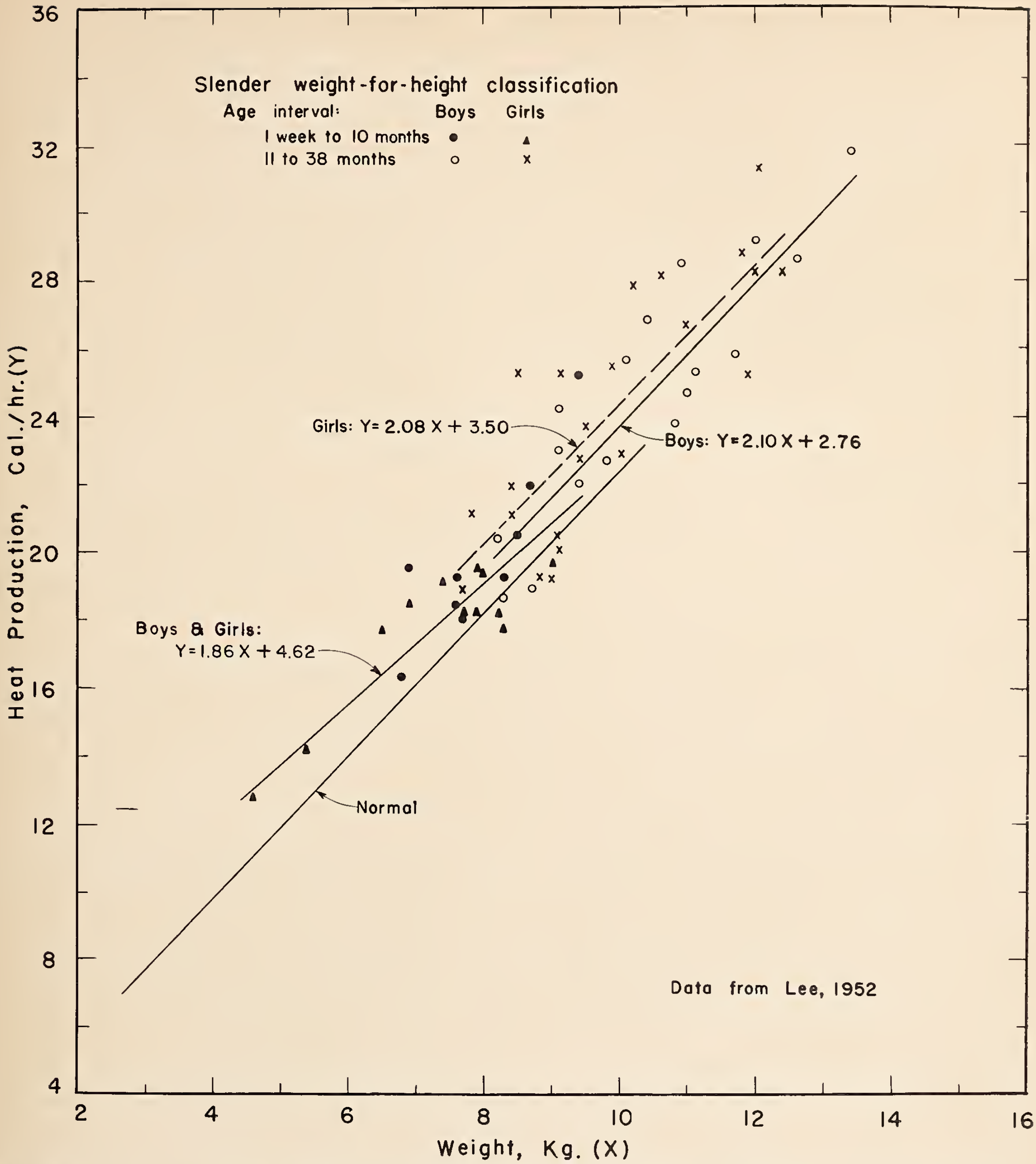

FIGURE 11.—COLORADO INFANTS WITHIN THE SLENDER WEIGHT-FOR-HEIGHT CLASSIFICATION: Scatter diagram and regression lines showing the relationship between basal heat production and weight.
The regression line for Normal infants, 1 week to 10 months of age, is shown for comparative purposes.

TABLE 6.—SLENDER WEIGHT-FOR-HEIGHT CLASSIFICATION: *Regression equations, standard errors of estimate, and correlation coefficients for the linear relationship between heat production and weight*

Investigator(s)	Age range	Weight range	Infants	Measurements	Regression equation Y=Calories/hr. X=Weight, kg.	Correlation coefficient[1]	Standard error of estimate
	Boys and girls: 1 week to 10 months						
	Months	*Kg.*	*Number*	*Number*			*Cal./hr.*
Benedict and Talbot (1921)	1/3–10	2. 7–10. 6	12	18	Y=2. 39X−0. 0078	0. 96	1. 37
Levine and Marples (1931)	4–10	5. 1– 7. 9	3	3	(2)		
Clagett and Hathaway (1941)	3–10	5. 0– 9. 0	4	20	(2)		
Benjamin and Weech (1943)	8–10	7. 0– 7. 7	1	3	(2)		
Lee (1952)	3–10	4. 6– 9. 4	14	21	Y=1. 86X+4. 62	. 83	1. 44
Above data combined	1/3–10	2. 7–10. 6	34	65	Y=2. 23X+1. 50	. 91	1. 42
	Boys: 11 to 38 months						
Benedict and Talbot (1921)	12–18	8. 5–10. 1	3	4	(2)		
Clagett and Hathaway (1941)	11	8. 9	1	1	(2)		
Benjamin and Weech (1943)	11–15	7. 9– 8. 0	1	4	(2)		
Lee (1952)	11–36	8. 2–13. 4	5	17	Y=2. 10X+2. 76	0. 90	1. 61
Above data combined	11–36	7. 9–13. 4	10	26	Y=2. 03X+3. 55	. 90	1. 50
	Girls: 11 to 38 months						
Benedict and Talbot (1921)	12–22	8. 1–10. 6	4	5	(2)		
Clagett and Hathaway (1941)	11–15	7. 8– 9. 1	2	10	(2)		
Lee (1952)	11–36	7. 7–12. 4	11	22	Y=2. 08X+3. 50	0. 81	2. 14
Above data combined	11–36	7. 7–12. 4	17	37	Y=1. 97X+4. 91	. 83	1. 80

[1] All significant at the 1-percent level.
[2] Number of measurements on a few infants too small for deriving separate equations but are included in the equations for the combined data.

mate from the regression line for the combined data on infants within the Normal weight-for-height classification.

The heat production of both Warren and George (fraternal twins) was relatively low compared with the regression line for infants within their respective weight-for-height classifications. The heat production per unit weight was slightly higher for George than for Warren. However, this was to be expected, since George was classified in the Slender and Warren in the Normal weight-for-height classification.

The heat production of identical twin girls approximates (within plus and minus one standard error of estimate) the regression line for Slender infants. Since the curves for these girls when older than 10 months of age show an upward trend more similar to those for boys (figure 6) than for girls (figure 5) in the Normal weight-for-height classification, the statement made earlier in regard to the sex difference is contradicted by these curves. The suggestions in the following reports might help to explain these differences.

Fleming (1923) suggested that the difference in temperament and environment probably accounted for the variation in the basal metabolism of individual persons—the metabolism of an "active, highly strung" child is higher than that of the lethargic child. This suggestion is substantiated by the following results on two white boys reported by Benjamin and Weech (1943). The heat production of the "uncooperative, irritable, unhappy, and tense" infant, who was "badly neglected at home," was somewhat higher than the average obtained for a Slender boy of his weight; it fluctuated greatly from day to day, reflecting his inability to relax, because "at no time, even during sleep, did he appear relaxed." Consequently, many of his tests were discarded during the 9 months he was under observation. At the other extreme, was a "docile and placid infant," whose heat production during the 2-month measurement period was somewhat lower than that obtained for the average boy in the Normal weight-for-height classification.

As mentioned earlier, data for infants within the *Stocky and Overweight classifications* were insufficient for statistical analysis. These data are presented in figure 13 in relation to the boundary lines of plus and minus one standard error of estimate from the regression line for infants within the Normal weight-for-height classification.

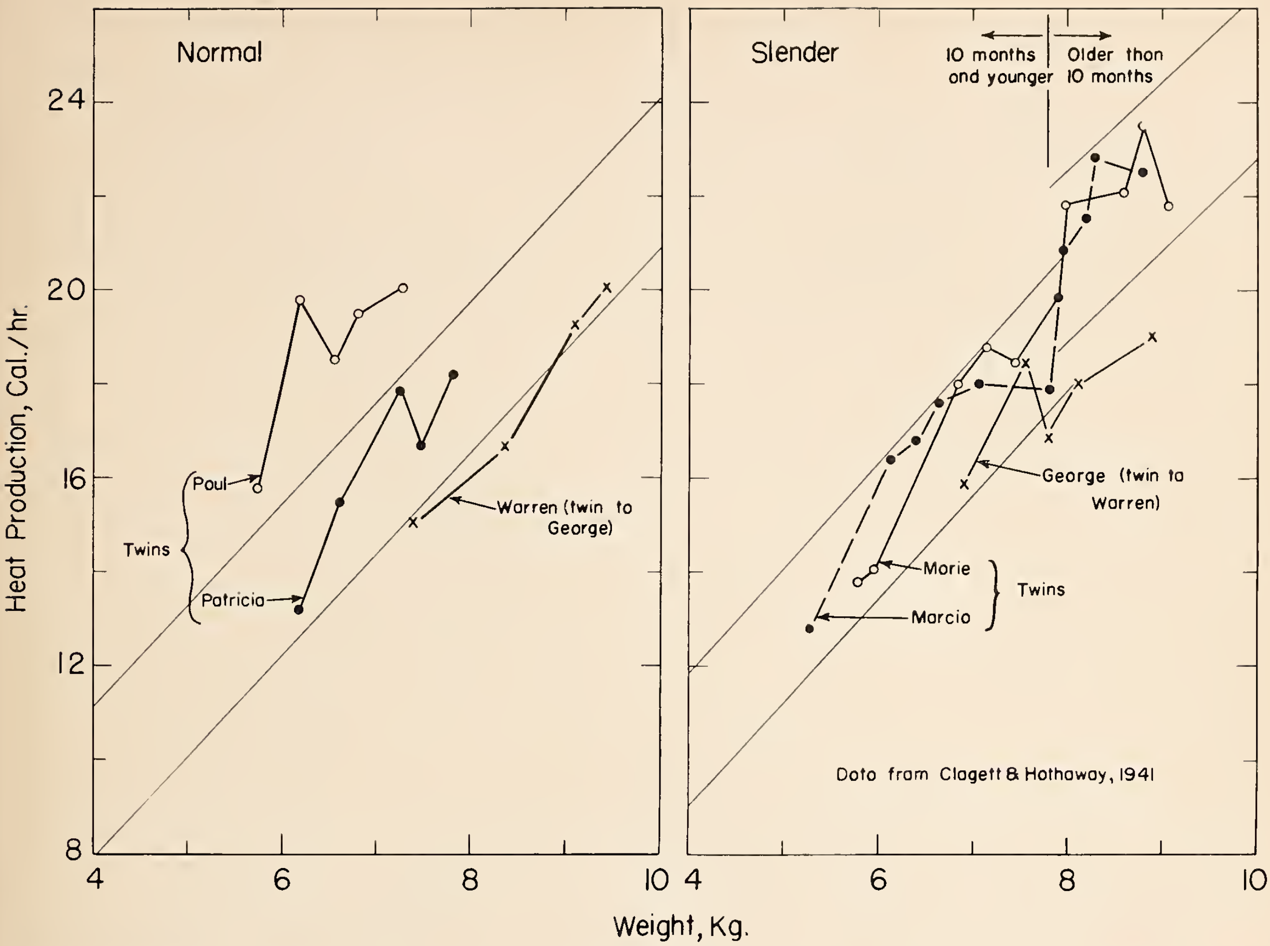

FIGURE 12.—NEW YORK TWIN INFANTS WITHIN THE NORMAL AND SLENDER WEIGHT-FOR-HEIGHT CLASSIFICATIONS: Basal heat production as function of weight.

Data point for individual infants are connected by lines. The area between the two parallel light lines represent plus and minus one standard error of estimate from the regression line for the combined data for the classifications and age intervals shown. (*See* tables 5 and 6.)

The data points for the Newborn infants in figure 13 fall within the range of plus and minus one standard error of estimate of the regression line shown. For the age interval 1 week to 10 months, some points are within the boundary lines shown but most fall below the line representing minus one standard error of estimate. A careful examination of the data revealed that many of the points falling outside the range of minus one standard error of estimate were obtained on infants described by the investigator as "fat" or "overweight"; furthermore, tests repeated at a later age indicated that they probably had been in this classification for at least 3 months. The points falling within the boundary lines shown were obtained on infants who were within the Stocky or Overweight classification for only one measurement (longitudinal data from Lee, 1952). This suggests that for the latter-mentioned infants, the weight gain was during an active developmental phase, whereas for the earlier-mentioned infants this was a stationary phase of overweight (*see* Holt and McIntosh, 1953).

The data points in figure 13 for Stocky and Overweight boys and girls within the age interval 11 to 38 months are decidedly below the area represented by plus and minus one standard error of estimate from the regression line shown for Normal boys and girls.

It is difficult to make an estimate for heat production of Overweight infants, but from the few data shown in figure 13 it appears that the regression line for Overweight infants (within the stationary phase) would roughly parallel that for Normal infants and would approximate the line drawn to represent minus two standard errors of estimate. On this basis, heat production of Overweight infants would be at least 3 Calories per hour lower than that for Normal infants of the same weight.

In summarizing the results on healthy infants, figure 14 shows the regression lines relating heat

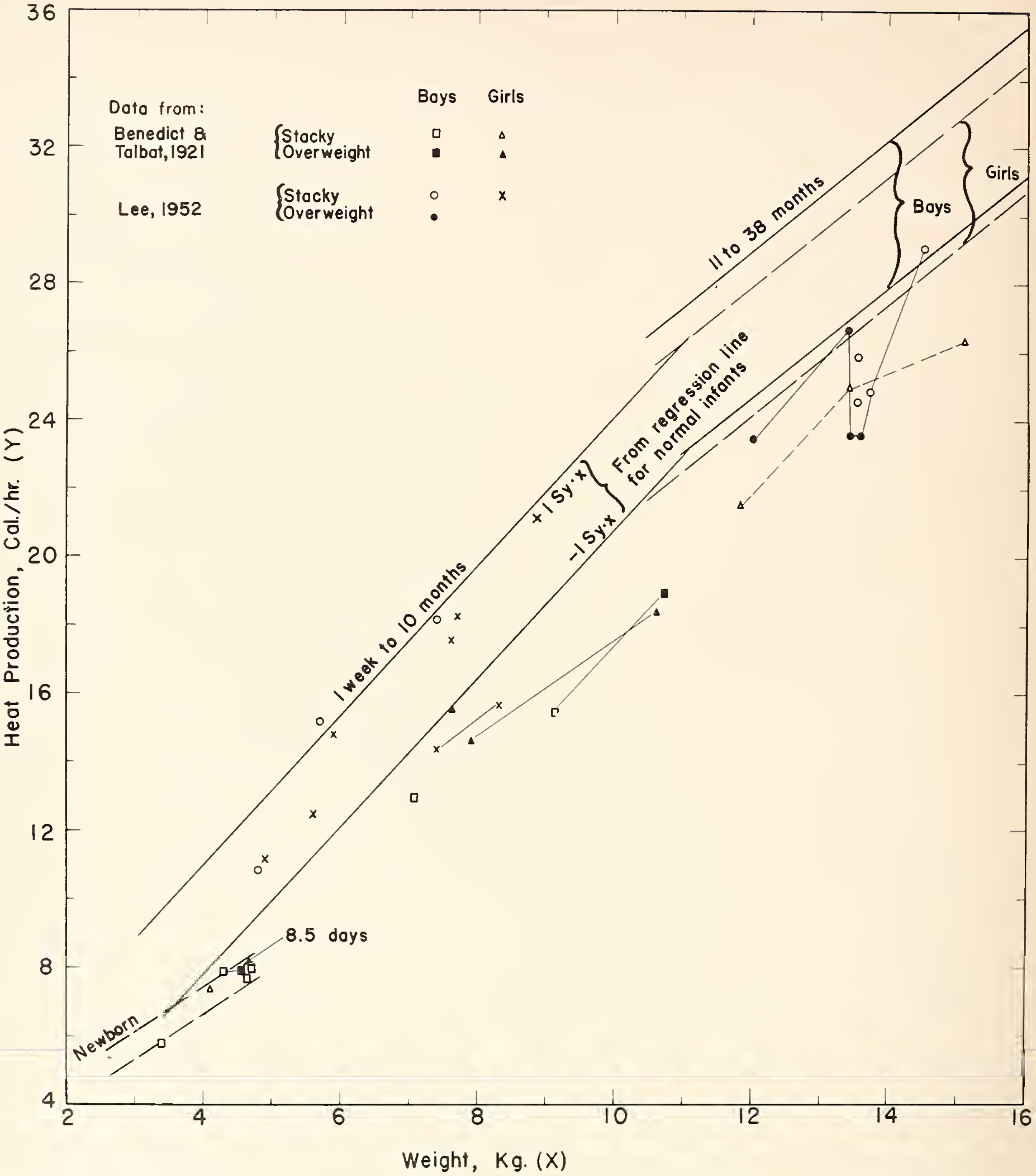

FIGURE 13.—STOCKY AND OVERWEIGHT WEIGHT-FOR-HEIGHT CLASSIFICATIONS: Scatter diagram showing the relationship between basal heat production and weight.

Data points for the same infant are connected by light lines. The two parallel lines represent plus and minus one standard error of estimate from the regression lines (combined data from all sources) for infants within the Normal weight-for-height classification. (*See* table 5.)

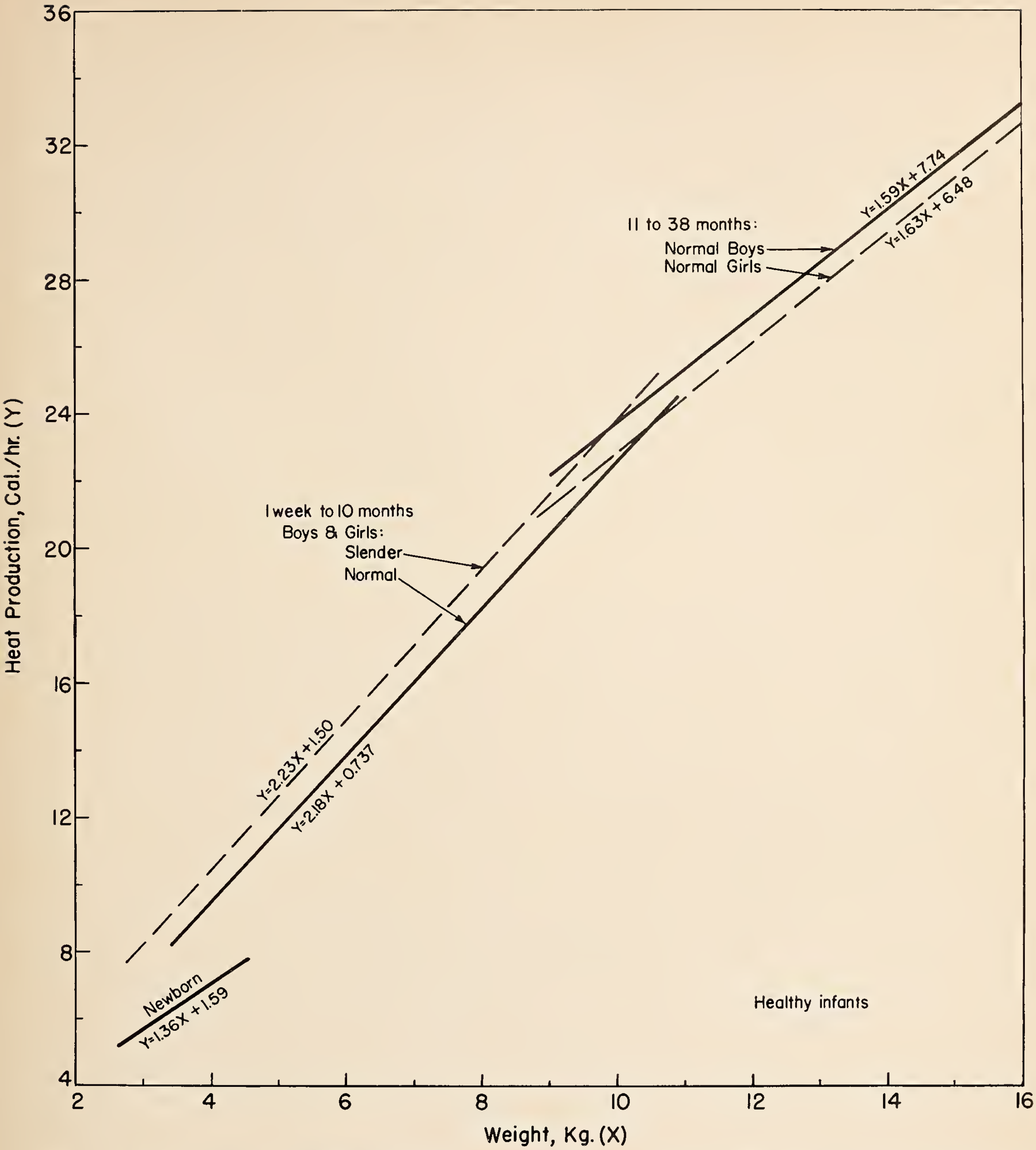

FIGURE 14.—HEALTHY INFANTS: Regression of heat production on weight for three age intervals and the Normal and Slender weight-for-height classifications.

The regression lines shown are those derived from the combined data (tables 5 and 6) with exception of the Newborn, which is represented by the equation (given in table 4) derived from the data of Benedict and Talbot (1915).

production to weight for the three age intervals. An outstanding feature of this figure is the relatively low position of the regression line for Newborn (under 1 week of age) infants in relation to the regression line for infants during the age interval 1 week to 10 months.

This Newborn age interval is considered a period in which the infant is making many physiological adjustments in adapting himself to new surroundings. The flatter slope of the regression line for the Newborn (full-term) infants in figure 14 indicates that the large (heavier weight) infants are affected more by birth than are small infants, since the difference in heat production between the Newborn and older infants is greater for large than for small infants. On the basis of regression lines given, heat production in a 4.5-kilogram Newborn infant is about 27 percent lower than that of an infant older than 1 week of the same weight; for a 2.5-kilogram Newborn infant, the reduction is about 20 percent (if the regression line for the older infant is extrapolated to include this lower weight). The weight loss at birth, which may be as much as 10 percent, is also greater in the large than in the small infant (Stuart and Stevenson, 1959).

After the adaptation of the Newborn infant to an extrauterine environment, heat production in the full-term infant increases at a constant rate of 2.2 Calories per hour for each kilogram increase in weight—a higher rate than during any other age interval. This rapid increase in heat production continues up to a weight of between 9 and 10 kilograms (which corresponds to an age of about 10 months). At this time, the heat production rate [4] changes to a lower rate—about 1.6 Calories per hour. Furthermore, at about the same age (10 months) a sex differentiation in heat production begins. Thus, the regression lines relating heat production to weight are parallel for boys and for girls, but the line for boys is at a higher elevation during the age interval 11 to 38 months (figure 14).

The weight-for-height classification apparently does not affect the heat production of Healthy infants below 1 week of age (no difference was found between Normal and Slender infants). But, following 1 week of age heat production for a given weight is slightly higher for Slender infants and lower for Stocky and Overweight infants (other than those in which the weight gain is of a temporary nature) than for infants within the Normal classification.

B. UNDERNOURISHED INFANTS

In early reports of heat production on infants, investigations of undernourished infants were frequent (*see* section I). Table 1 shows that values for 40 Underweight infants were available from the investigations of Benedict and Talbot (1914a; 1914b). In addition, Talbot (1921) reported results on severe infantile malnutrition, and Levine *et al.* (1928a) and Watt *et al.* (1932) reported results on "marantic" or "emaciated" infants.

The majority of these undernourished infants were within the Underweight classification; [5] yet, they may not be a homeogenous group because the degree of severity ranged from loss of weight because of underfeeding to an emaciated condition of extreme wasting, devoid of all subcutaneous fat. The degrees of severity in undernourished infants described by Benedict and Talbot were as follows:

> Infantile atrophy is applied to the condition of an emaciated infant with such severe indigestion that it is unable to digest weak mixtures of cow's milk, with no gain in weight, and with a subnormal body-temperature. The convalescent stage of infantile atrophy is that in which the same infant subsequently begins to digest its food and to gain weight and has a normal temperature. Underweight infants are those who are 0.5 kilogram or more below the average weight for their respective ages but whose digestion is not so severely deranged as with infantile atrophy.

Levine *et al.* (1928a) concluded from a study of marantic infants that "the character of the fundamental metabolism apparently remains normal in marasmus, and the production of heat per kilogram of active protoplasmic tissue appears to be essentially the same in this condition as in health." (*See* also Wilson *et al.*, 1928; Levine *et al.*, 1928b.) Earlier Fleming and Hutchinson (1924) made similar conclusions from studies on undernourished infants. On the basis of these reports it is assumed that the heat production for the majority of these infants was not deranged, although it is appreciated that a few of the infants in this undernourished group may have had physiological abnormalities or have been pathological cases (*see* table 1). Fleming and Hutchinson also reported that the basal metabolic rate of undernourished infants with pathological conditions (other than diabetes, thyroid disease, and fevers) "corresponded closely with the rate found in uncomplicated marasmus."

Because of the range in degree of malnutrition, these data on heat production of Undernourished infants are not statistically analyzed, but are shown in relation to the regression line for healthy infants within the Normal weight-for-height classification. Figure 15 shows a scatter diagram of heat production plotted in relation to weight for Undernourished infants within the Underweight or Slender weight-for-height classifications. The age range represented by these infants was 2 to 17 months. Note that the eight infants between 11 and 17 months of age weighed less than 8.2 kilograms. The boundary lines of plus and minus

[4] Heat production *rate* as used herein refers to the increase in heat production per unit increase in weight; it is the value of b (the slope of the line) in the regression equation $Y=a+bX$. This terminology should not be confused with the term "*basal metabolic rate*" commonly used to denote the percentage deviation between the observed and predicted values of heat production.

[5] Data from Talbot (1921) could not be classified but were presumed to be Underweight since "severe cases of infantile malnutrition" were investigated.

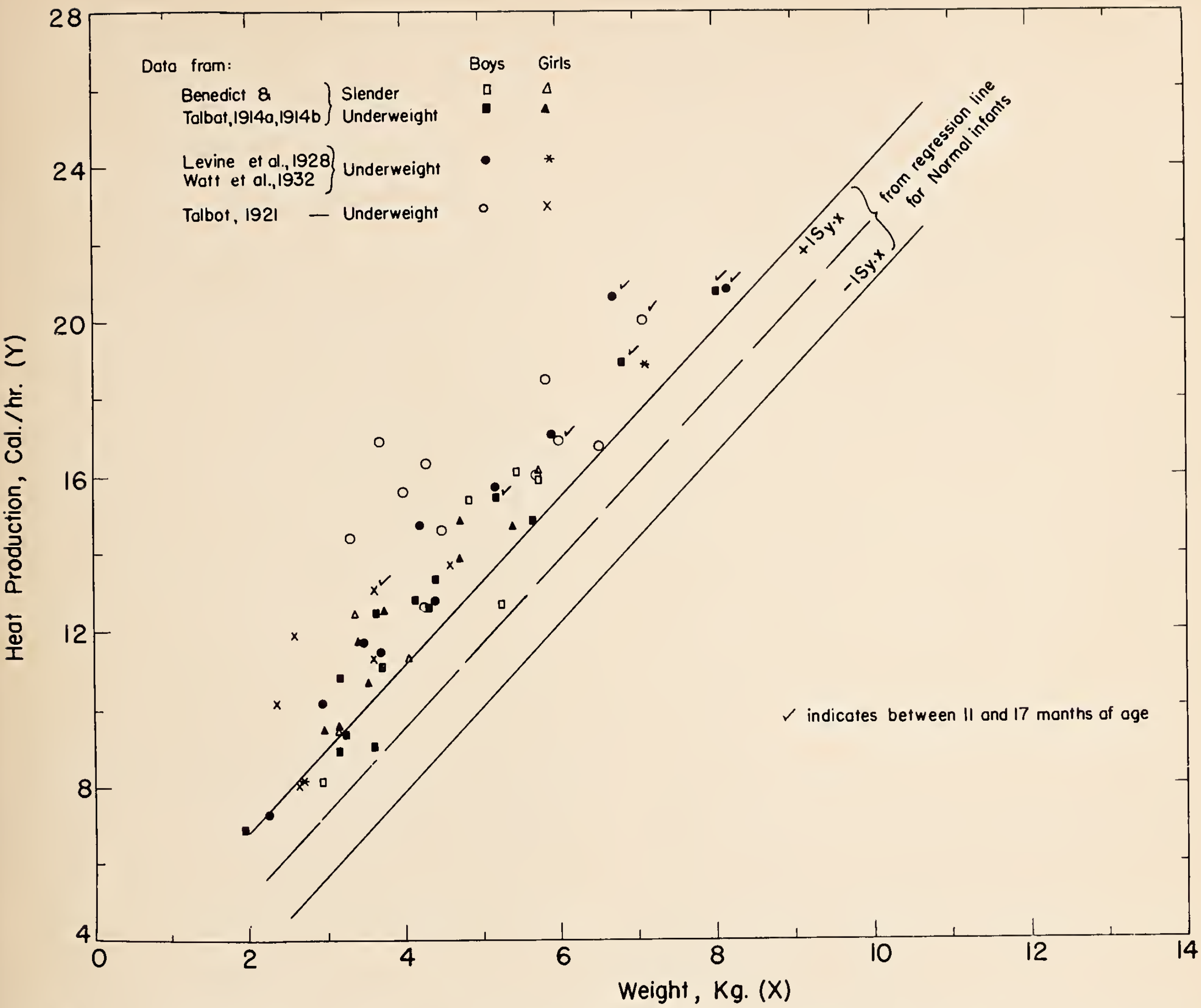

FIGURE 15.—UNDERNOURISHED INFANTS: Scatter diagram showing the relationship between basal heat production and weight.

The two parallel lines represent plus and minus one standard error of estimate from the regression line (combined data from all sources) for Healthy infants within the Normal weight-for-height classification. (*See* table 5.)

one standard error of estimate from the regression line derived for Normal infants within the 1 week to 10 month age interval are shown for comparative purposes. All but about one-sixth of the data points are above the boundary line representing plus one standard error of estimate. Note that the data points for Talbot's (1921) cases of "severe infantile malnutrition" are, on the average, somewhat higher than the other data points.

These data in figure 15 indicate that for a given weight, Underweight infants have a higher heat production than do Normal infants. If a regression line were fitted to these data regardless of degree of underweight, it would parallel the regression line for the Normal classification but be at an elevation somewhat above the line for plus two standard errors of estimate from the regression line for Normal infants (or plus one standard error of estimate from the line for Slender infants). It is estimated that heat production for Underweight infants would be at least 3 Calories per hour (75 Calories per day) more for infants of the same weight within the Normal weight-for-height classification or at least 2 Calories per hour (50 Calories per day) more than for Slender infants of the same weight.

On the basis of the foregoing estimates, an Underweight infant would have the same total heat production as a Normal infant of the same height (and within the same age interval) but weighing 1.5 kilograms more. If the weight difference between the two infants (of the same height) was greater than 1.5 kilograms, the heat production of the Normal infant would be slightly more than that for the Underweight; but if the weight difference was less, it would be less than that for the Underweight infant.

Several recent reports (Goldsmith, 1959; Nelson, 1959) have stated, without defining reference unit, that in severe malnutrition basal metabolism declines. Heat production is a function of weight; therefore, when there is a decline in weight as in malnutrition, there would be a corresponding decline in heat production. However, per kilogram of body weight, basal metabolism is higher for the malnourished than for the healthy infant (Talbot, 1921; Levine *et al.*, 1928a). Thus, the importance of designating the reference unit for body size is obvious when reporting values for heat production.

C. PREMATURE INFANTS

The investigators reporting data on heat production of premature infants and the pertinent details involved are given in table 1 (part C). The number of measurements on heat production of premature infants available for this analysis are shown in table 7. The widely-used criterion for establishing prematurity is a birth weight of 2.5 kilograms (5½ pounds) or less (Holt and McIntosh, 1953). This criterion was followed by most investigators reporting data on premature infants. However, if data were reported for infants weighing more than 2.5 kilograms at birth, they were omitted from this analysis on premature infants.

Postnatal growth of the premature differs from that of the full-term infant (Watson and Lowrey, 1954). However, premature infants are classified herein according to the weight-for-height classification set up for full-term infants, since data are not available for establishing a separate classification. On the basis of this classification, the premature infants (for which height was reported—Talbot *et al.*, 1923; Gordon and Levine, 1936) were classified as Underweight during the first month of age with the exception of three infants, who were in the Slender classification but near the borderline separating the Slender and Underweight. If height was not reported, the premature infant was assumed to be Underweight. A few infants measured at repeated intervals showed a change from a Slender or Underweight classification to a Normal one after about 1 month of age; these measurements, which were made while in the Normal classification, were not included in the analysis.

Whereas the majority of the full-term infants were within the Normal weight-for-height classification (*see* table 3), the premature infants were usually within the Underweight classification. This difference in the weight-for-height relationship between the premature and the full-term infant suggests that the body composition may be somewhat different, especially when it is realized that in the normal fetus, subcutaneous fat does not accumulate much before the eighth lunar month (Watson and Lowrey, 1954). Therefore, the premature infant "has little or no inactive fat and is largely composed of muscle and organs" (Talbot, 1925).

That body composition is different for premature and full-term infants was recognized by Gordon *et al.* (1940) in comparing the heat production of infants, and was confirmed by the data on the percentage of fat in the body by McCance and Widdowson (1951). These workers reported that in the average full-term infant (3.5 kilograms) the percentage of fat is about the same as that in the average adult man or woman—16 percent; whereas in the premature infant weighing 2.5 kilograms it is about 9 percent and for (the premature infant) one weighing 1.5 kilograms, 4 percent.

This low fat percentage indicates that if Underweight premature infants are to attain a Normal weight-for-height relationship, the increase in weight must be out-of-proportion to their increase in height, that is, as compared with the relationship between weight and height for the average full-term infant. Thus, the weight-for-height classification presented herein for infants may not be applicable to premature infants.

TABLE 7.—*Basal metabolic measurements*[1] *analyzed on Premature infants*[2]

[Measurements made while asleep and after feeding unless otherwise indicated.]

Investigator(s)	Age interval: Birth to 10 days (boys and girls)	Age interval: 11 days to 3 months (boys and girls)	Total
	Number	*Number*	*Number*
Talbot, Sisson Moriarty, and Dalrymple (1923).	7	30	37
Marsh and Murlin (1925)	20	8	28
Gordon and Levine (1936)	13	[3] 20	78
Gordon, Levine, Deamer, and McNamara (1940).	0	7	
Dann, Kelly, McNamara, and Curtis (1942).	0	12	
Day (1943)	14	12	
Miller, Behrle, Hagar, and Denison (1961).	8	0	8
Total	62	89	151

[1] Measurement is used herein to indicate one test, or an average of several tests, made at a specified age. Tests repeated on the same infant at a later age were considered another measurement. Measurements on the same infant sometimes were made within a day or two; for infants under 1 month, measurements were used as reported but for infants older than 1 month, they were averaged by months.

[2] Within the Underweight classification (with few exceptions which were in the Slender) for those for which height was reported.

[3] Three measurements on infants within the Normal weight-for-height classification not included.

Whereas weight for height of the growing healthy full-term infant progresses parallel, or nearly parallel, to the line of average relationship (*see* figure 3), the line representing weight for height in the growing premature infant is much steeper. Thus, for the premature the percentage increase in weight per unit increase in height is greater.

The premature infant may shift his weight-for-height classification from a position near the lower borderline of the Underweight classification to one near the upper borderline; then, with increasing age, on to a Slender classification, and, perhaps, to a Normal classification. The length of time required for this shift to occur probably depends, in part, upon the degree of prematurity. The shift from an Underweight to a Slender classification took place between 12 and 19 days for seven infants (birth weights ranged from 1.6 to 2.2 kilograms) as shown from repeated measurements in the data of Gordon and Levine (1936).

Presumably, a stabilization in a Normal or Slender classification (that is, a weight-for-height relationship parallel to the average line shown in figure 3) is reached before normal physical size for age is attained. Watson and Lowrey (1954) reported that "An average period of two years for girls and three years for boys may intervene before that goal is reached," and that the smallest premature may take from 8 to 10 years to attain normal weight for age.

Heat production as a function of weight for premature infants is shown in figure 16. The data reported by the investigators working at Cornell University Medical Laboratory (Gordon and Levine, 1936; Gordon *et al.*, 1940; Dann *et al.*, 1942; and Day, 1943) were combined as the apparatus and procedure were apparently identical, with the exception of the 1936 report for which the closed-circuit type of apparatus was used (*see* table 1). However, these data are comparable with those for which the open-circuit type was used.

The time required for the newborn to adapt to extrauterine life is longer for the premature than for the full-term infant. From the data summarized herein, heat production in the premature

TABLE 8.—PREMATURE INFANTS: *Regression equations, standard errors of estimate, and correlation coefficients for the linear relationship between heat production and weight*

[Data for boys and girls combined.]

Investigator(s)	Weight-for-height classification	Age range	Weight range	Infants	Measurements	Regression equation Y=Calories/hr. X=Weight, kg.	Correlation coefficient [1]	Standard error of estimate
		Birth to 10 days, inclusive						
		Days	*Kg.*	*Number*	*Number*			*Cal./hr.*
Talbot, Sisson, Moriarty, and Dalrymple (1923).	Underweight.	3–10	1.2–1.9	7	7	[2]		
Marsh and Murlin (1925)	[3]	3–9	1.6–2.7	11	20	$Y=1.78X+0.570$	0.81	0.37
Gordon and Levine (1936)	Underweight.	1½–8	1.3–2.2	13	13	$Y=2.90X-1.079$ (Gordon and Levine; Day)	.73	.77
Day (1943)	[3]	4–10	1.9–2.4	13	14			
Miller, Behrle, Hagar, and Denison (1961).	[3]	½–2	[4] 1.7–2.4	8	8	[5]		
		Older than 10 days						
Talbot, Sisson, Moriarty, and Dalrymple (1923).	Underweight.	11–97	1.2–3.0	16	30	$Y=3.06X-1.752$	0.87	0.70
Marsh and Murlin (1925)	[3]	11–14	2.2–3.2	6	8	[2]		
Gordon and Levine (1936)	Underweight.[6]	12–67	1.3–2.9	17	20	$Y=2.80X-0.491$ (Gordon and Levine through Day)	.88	.55
Gordon, Levine, Deamer, and McNamara (1940).	[3]	10–65	2.0–2.5	7	7			
Dann, Kelly, McNamara, and Curtis (1942).	[3]	10–75	1.9–2.8	10	12			
Day (1943)	[3]	11–35	1.4–2.8	10	12			

[1] All significant at the 1-percent level.
[2] Number of measurements on a few infants too small for deriving a separate equation comparable to the others.
[3] Height not reported; therefore, classification could not be determined.
[4] Birth weight.
[5] In addition to the limited number of measurements in this group, the age range was only 2 days and the weight at time of measurement was not given; therefore, these data are not comparable with the data in any of the other groups.
[6] Includes 8 measurements on Slender infants—at least half had been Underweight at younger ages.

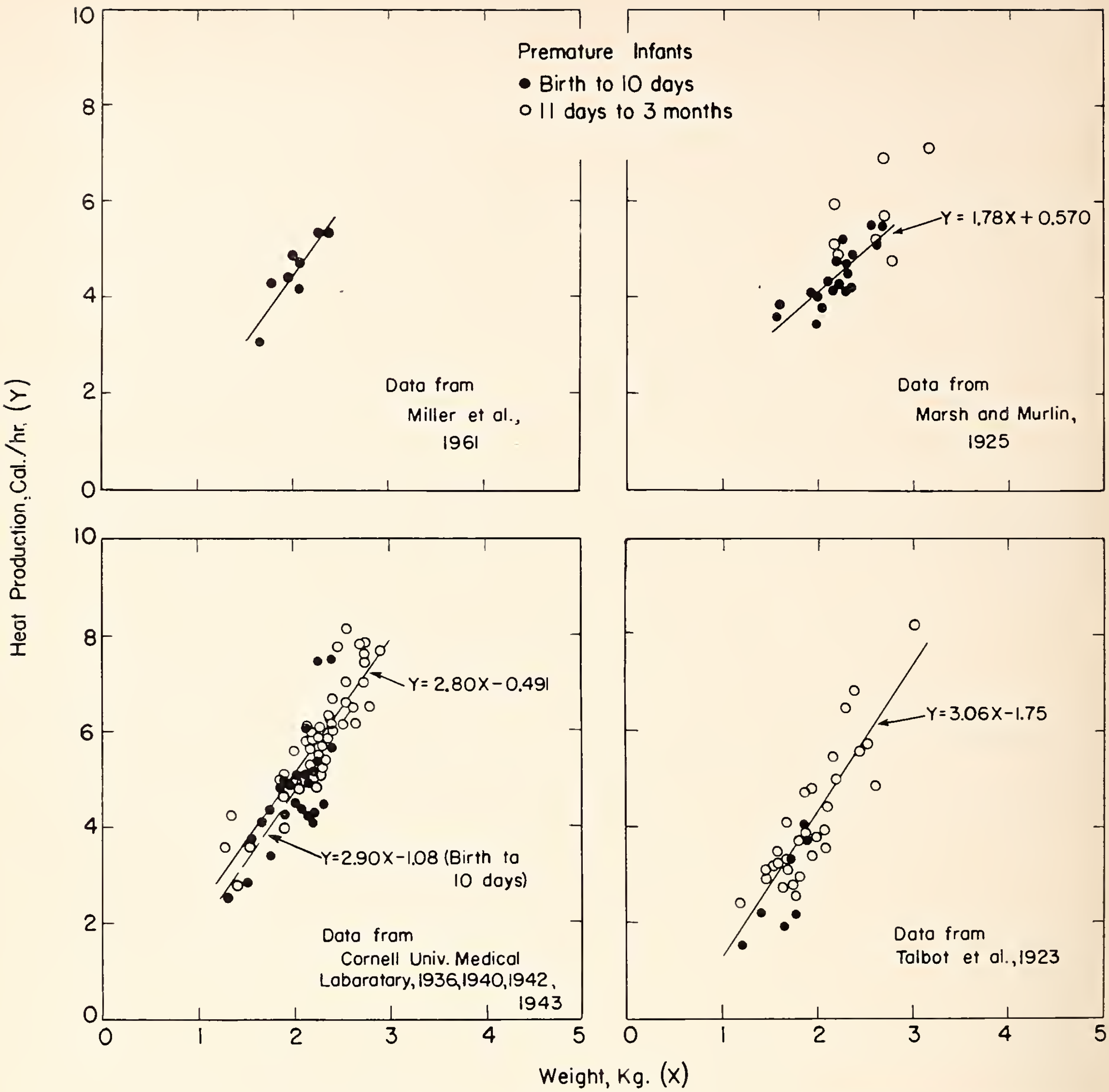

FIGURE 16.—PREMATURE INFANTS: Scatter diagrams and regression lines showing the relationship between basal heat production and weight.

Measurements reported by Miller *et al.* (1961) were made on infants less than 2 days old and are shown as function of birth weight rather than actual weight at time of measurement. Data sources are indicated on the chart. Cornell University Medical Laboratory represents the combined data from Gordon and Levine (1936); Gordon *et al.* (1940); Dann *et al.* (1942); and Day (1943).

infant increased, on the average, following the 10th day. Thus, the length of the Newborn age interval for the premature has been extended to include the 10th day. This agrees with Talbot's (1921) report on premature infants that the lowest heat production was in the first 10 days of life, and is in accord with the longer time required by the premature to regain its birth weight (Watson and Lowrey, 1954).

The regression line for Newborn premature infants is at a slightly (but statistically significant) lower elevation than the regression line for the older premature infants (lower left section of figure 16); however, the lines are parallel; that is, they have similar slopes. This relation between the regression lines derived for the two age intervals is unlike that for the full-term infants. The line for the Newborn full-term infants was

not only lower but had a flatter slope in relation to that for the older full-term infant.

Table 8 and figure 16 show that the regression equation fitted to the data of Marsh and Murlin (1925) for Newborn infants (birth to 10 days old, inclusive) has a flatter (but statistically insignificant) slope than that of the other Newborn group. This regression line is also at a significantly lower elevation (*see* results of covariance analysis in the appendix, table 15). Thus, this equation is more similar to the regression equation for the Newborn full-term infants (table 4) than to the regression equation for the Newborn premature infants (Cornell University Medical Laboratory). The explanation may be associated with the difference in body size and physiological maturity. Marsh and Murlin's group of infants weighed more at birth than the other groups and 3 of the infants were full-term but "undersized" as shown in table 9. Furthermore, 6 of 21 infants in the Gordon and Levine (1936) group as compared with 12 of 15 infants in the Marsh and Murlin group weighed over 2.0 kilograms at birth. Therefore, the Marsh and Murlin premature infants more nearly resemble the average full-term infants than the other premature infants.

The slope of the regression lines relating heat production to weight for premature infants was near 3.0 (figure 16). For full-term infants (table 5) the slope was 2.2. Thus, heat production in relation to weight increases at a faster rate in the premature than in the full-term infant. This faster rate is to be expected, since in the premature the energy requirement for growth may double that of the normal Newborn infant (Watson and Lowrey, 1954). Furthermore, the weight-for-height classification of the premature is shifting from Underweight, to Slender, to Normal, whereas that for the average full-term infant is stationary within a given classification.

The elevation of the regression line derived from the data of Talbot *et al.* (1923) was significantly lower than that for the combined data from the Cornell University Medical Laboratory. Since the procedures were similar (*see* table 1), the explanation must be either a difference in the rate of growth or in the degree of prematurity. Although the birth weight and weight range of the infants were similar for both groups, the infants from Talbot's groups apparently grew more slowly since they were Underweight throughout the age interval studied (97 days), whereas one infant in the Gordon and Levine (1936) study progressed from an Underweight to a Normal weight-for-height classification in 47 days and another, from Slender to Normal in 26 days.

The conclusion from these data is that heat production in Premature infants, as compared with Healthy full-term infants, increases at a faster rate per unit increase in weight in accord with the faster growth rate and with the shift upwards from one weight-for-height classification to another. Presumably, when stabilization in a particular classification is reached (that is, increase in weight for height is parallel to the average relationship between weight for height), the heat production rate in the premature may change to the lower rate characteristic of full-term infants. Talbot (1925) reported that the heat production of the premature infant "sometimes toward the end of the first or second year reaches that of the normal infant." This age span is somewhat shorter than the average time required for a premature to reach the normal physical size, but may correspond to the time at which a Normal weight-for-height classification is reached.

TABLE 9.—*Birth weights of Premature infants*

Investigator(s)	Infants weighed	Birth weight		Infants with birth weight 2.0 kg. and over
		Average	Range	
	Number	*Kg.*	*Kg.*	*Number*
Talbot, Sisson, Moriarty, and Dalrymple (1923).	17	1. 72	1. 2–2. 1	1
Marsh and Murlin (1925).	[1] 15	2. 13	1. 6–2. 5	12
Gordon and Levine (1936).	21	1. 85	1. 4–2. 2	6
Gordon, Levine, Deamer, and McNamara (1940).	7	1. 70	1. 1–2. 2	2
Dann, Kelly, McNamara, and Curtis (1942).	10	1. 78	1. 1–2. 2	4
Day (1943)	22	(2)		
Miller, Behrle, Hagar, and Denison (1961).	8	2. 03	1. 7–2. 4	5

[1] Included one pair of full-term twins and one full-term infant with a birth weight less than 2.5 kilograms.

[2] Individual birth weights were not given, but reported to have been less than 2.5 kilograms. The weight range (shown in table 8) at the time of measurement is very near that of Gordon and Levine (1936), and 2 infants at 14 and 17 days weighed 1.44 and 1.52 kg., respectively.

IV. Discussion

The results summarized herein indicate that the regression line relating heat production to weight for infants older than 1 week of age was at a significantly higher elevation for Slender infants than for infants within the Normal weight-for-height classification but that the increase in heat production per unit increase in weight was the same (*see* appendix, table 13). However, for children 2 years of age to puberty, the difference in elevation between these classifications was not statistically significant (*see* Sargent, 1961).

No explanation can be offered for this discrepancy in the results for Normal and Slender *infants*, 1 week to 38 months of age, as contrasted with those for Normal and Slender *children* 2 years of age to puberty. However, the higher heat production of Slender infants fits in with the theory that heat production is related to the amount of active protoplasmic tissue (for example, *see* Talbot, 1933). Thus, an infant in the Slender weight-for-height classification weighs less for a given height than an infant in the Normal classification; hence, the Slender infant has a relatively greater proportion of active protoplasmic tissue per unit weight, and in accordance with the theory, a slightly higher heat production for a given weight than the Normal infant.

The data on Stocky and Overweight infants lend support to this protoplasmic theory. Stocky and Overweight infants weigh more for a given height than infants within the Normal weight-for-height classification, and therefore, theoretically, they have a smaller proportion of protoplasmic tissue per unit weight. The data herein indicate that heat production was less for the Stocky and Overweight infant than for the Normal infant of the same weight. These results are substantiated by those in the preceding report (Sargent, 1961) for children 2 years of age to puberty. The regression lines relating heat production to weight were at lower levels for children within the Stocky and Overweight classifications than for children within the Normal weight-for-height classification.

Karlberg's (1952) recent results on the heat production of Swedish infants 1 week to 11 months of age are enlightening, although not comparable to those reported herein, because the infants were fasted 4 to 6 hours and a sedative (a barbituric acid preparation) was administered to keep the infant quiet. He reported that the relation between heat production and weight was "nearly linear but became increasingly curvilinear with increasing body weight." A multiple regression (logarithmic) equation based on both weight and height was considered a significantly better fit of the data than logarithmic equations based on weight or height separately. In addition to these logarithmic equations, a linear equation relating energy metabolism to "electrical capacitance surface" was derived. This was found to give a "prediction precision equal" to the aforementioned multiple regression equation.

Figure 17 shows the linear regression line relating heat production to weight derived from Karlberg's (1952) data on 48 infants measured while fasting and during "superficial sleep" along with the equation derived for United States infants measured after feeding and while asleep. The slopes of these regression lines were not significantly different, but the elevation of the regression line for the infants measured while asleep was from 7 to 9 percent lower (at 4 and 10 kilograms weight, respectively) for the fasted (Swedish) infants than for the fed (United States) infants. This difference in heat production between fed and fasted infants may be attributed to the specific dynamic action of food, since Karlberg maintained that the low doses of sedative administered did not influence the energy metabolism.

This average value of 8 percent attributed to the specific dynamic action of food is somewhat lower than that previously reported herein for Newborn infants (heat production of new born infants not fed was from 12 to 15 percent lower than for fed infants), but agrees with the usual allowance of 6 or 8 percent of the calories for the specific dynamic action when more than 12 percent of the calories are from protein (Du Bois, 1936).

Levine *et al.* (1927) reported that when the caloric intake in a mixed diet was increased 2-, 3-, and 4-fold, the increase in heat production was 4, 6, and 9 percent, respectively, above the basal value (measurements made 2 to 3 hours after a small meal of cow's milk). In a later study (Levine *et al.*, 1935) on five infants the average percentage increment following a maintenance meal was 11 percent (range of 6 to 14 percent) above the basal level; and in daily balance studies on a normal diet 9 percent of the total daily calories were attributed to the specific dynamic action of food.

Figure 17 shows that the regression lines representing Preschool boys and girls are at higher

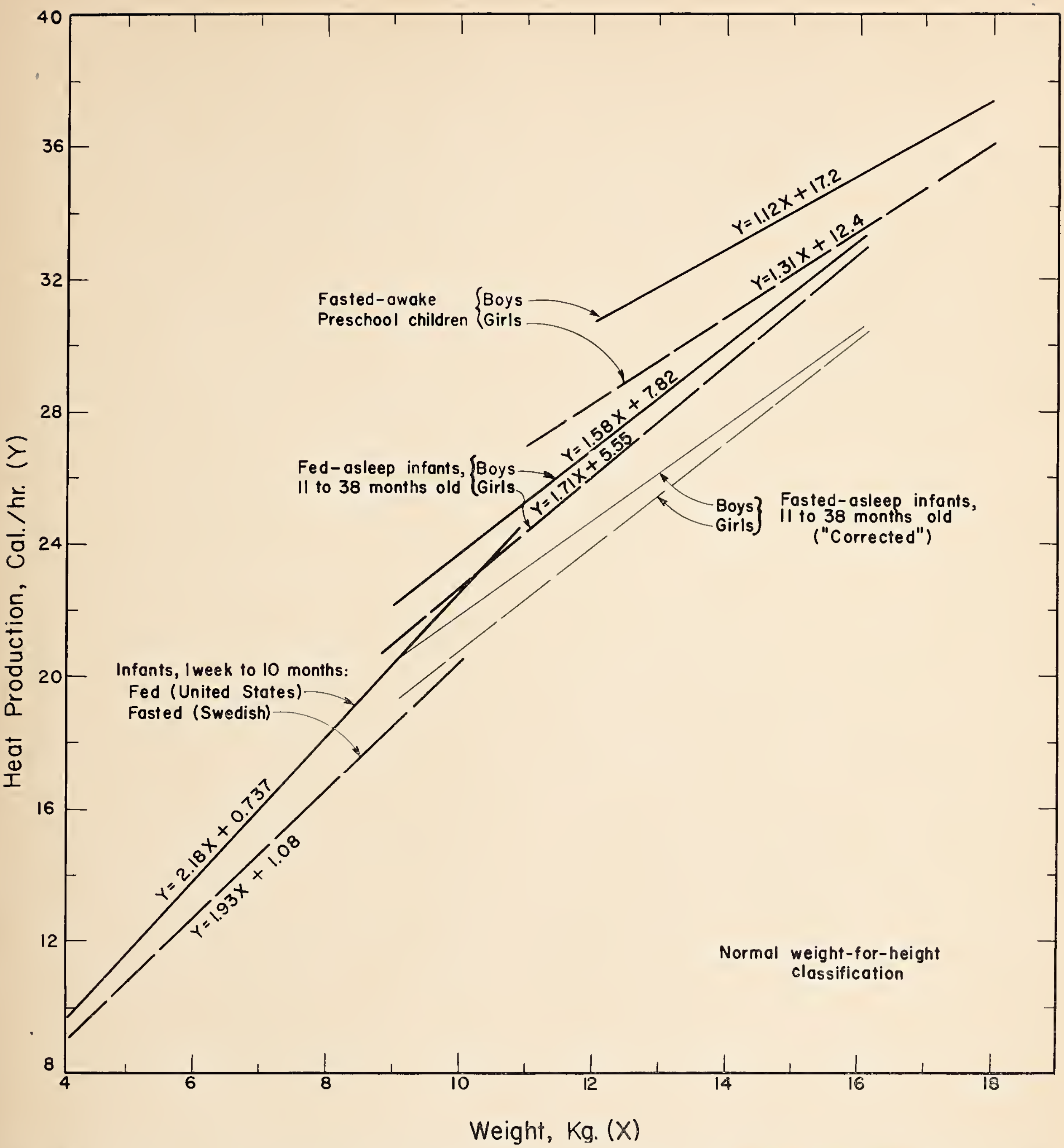

FIGURE 17.—Heat production as function of weight for fed and fasted infants measured while asleep and for fasted Preschool children measured while awake.

The line for the fasted (Swedish) infants was fitted to the data from Karlberg (1952); the line for the fed (United States) infants, 1 week to 10 months of age, represents the combined data from all sources (*see* table 5); the line for the infants, fed and asleep, 11 to 38 months of age, was derived for Colorado boys and girls from the data of Lee (1952); the line for the Preschool children (2 to 4½ years of age) also represents Colorado boys and girls. (*See* Sargent, 1961.) The regression lines shown for boys and girls, "fasted and asleep," were "corrected" to exclude the specific dynamic action of food (8 percent of the basal heat production was deducted from the equation for infants, fed and asleep).

elevations than are the regression lines representing infants, 11 to 38 months of age. The Preschool children were measured while fasting and awake, whereas the infants were measured after feeding and while asleep. On a percentage basis, heat production of the Preschool children, fasted and awake, is higher than that for the infants, fed and asleep, by 14 and 6 percent for boys and

8 and 2 percent for girls at 12 and 16 kilograms weight, respectively—the range of the overlapping weight interval.

In this connection, Lee and Iliff (1956) reported that the mean of tests made on fed infants, 21 to 36 months of age, while asleep were 3 to 9 percent lower than the mean of tests made on the same infants (but not at the same age) when fasted and awake. Thus, sleep, apparently, depresses heat production to a greater extent than the ingestion of food stimulates it. Therefore, the depressing effect of sleep is not counterbalanced by the stimulating effect of food as commonly thought. This misconception may have arisen, in part, to justify the practice of feeding the infant so he would remain quiet during the test period, and in part, by ignoring the latter part of the statement (*see* page 1) made by Benedict and Talbot (1921) regarding the influence of food and sleep on basal heat production measurements of infants.

If the regression lines representing heat production of fed infants measured while asleep were "corrected" to a fasting condition by deducting from the basal heat production 8 percent for the stimulating effect of food, the resulting line would represent the heat production of fasting infants while asleep. This "corrected" regression line is from 19 to 13 percent lower for boys and 15 to 10 percent lower for girls at 12 and 16 kilograms, respectively, than the line representing the fasted Preschool children measured while awake (*see* figure 17). Thus, the average decrease in basal heat production associated with sleep is estimated to be about 15 percent.

This decrease in basal metabolism associated with sleep in infants and small children is in line with conclusions from other studies. Measurements by Benedict (1922) on two newborn infants indicated a decrease during sleep of 5 and 13 percent. Wang and Kern (1926) reported that the average heat production of five boys and seven girls, 4 to 10 years of age, decreased 15 percent (range of 5.7 to 31 percent) during sleep. Williams (1934) reported that the average increase from a sleeping level to a waking level in fed children, 3 to 4 years of age, was 19 percent (range of 3 to 35 percent for the individual measurements).

The percentage decline in heat production while asleep was slightly greater for boys than for girls. This is explained by the smaller difference associated with sex in the 11- to 38-month-old infants as compared with a greater sex difference for the Preschool children. It was shown previously that sex begins to exert an influence at about 10 or 11 months of age and, apparently, increases with advancing age. However, within a given age interval, the slopes of the regression lines for the boys and for the girls were not significantly different.

Heat production is estimated to be about 0.8 Calorie per hour higher for boys than for girls of the same weight within the age interval of 11 to 38 months (a difference significant at the 5-percent level); whereas, heat production averaged about 2 Calories per hour higher for boys than for girls of the same weight within the Preschool age interval (a difference significant at the 1-percent level). A value of 3.0 Calories per hour was estimated to be the difference between boys and girls within the School Age to Puberty age interval (*see* Sargent, 1961).

It is inferred that the steeper slopes of the regression lines for the infants (fed and asleep) in figure 17 (as compared with those for the Preschool children) are primarily due to the greater heat production associated with feeding, since the regression lines "corrected" to eliminate the specific dynamic action are more nearly parallel to the lines representing the Preschool children. Therefore, the increase in heat production per unit increase in weight is the same from age 11 months to 4 or 4½ years, at which time there is a change to a lower rate (*see* Sargent, 1961).

Table 10 gives calculated values of heat production for each 0.5 kilogram weight. These

TABLE 10.—*Predicted basal [1] heat production of full-term infants, 1 week of age and older and within the Normal weight-for-height classification [2]*

Weight in kilograms	1 week to 10 months [3]	Weight in kilograms	11 to 38 months [4]	
	Boys or girls		Boys	Girls
	Cal./hr.		*Cal./hr.*	*Cal./hr.*
3.5	8.4	9.0	22.0	21.2
4.0	9.5	9.5	22.8	22.0
4.5	10.5	10.0	23.6	22.8
5.0	11.6	10.5	24.4	23.6
5.5	12.7	11.0	25.2	24.4
6.0	13.8	11.5	26.0	25.2
6.5	14.9	12.0	26.8	26.0
7.0	16.0	12.5	27.6	26.9
7.5	17.1	13.0	28.4	27.7
8.0	18.2	13.5	29.2	28.5
8.5	19.3	14.0	30.0	29.3
9.0	20.4	14.5	30.8	30.1
9.5	21.4	15.0	31.6	30.9
10.0	22.5	15.5	32.4	31.7
10.5	23.6	16.0	33.2	32.6
11.0	24.7			

[1] "Basal" heat production for infants includes the specific dynamic action of food and the measurements are made while the infant is sleeping quietly.

[2] *See* figures 3 and 4 for classification. For infants within the Slender weight-for-height classification, the heat production would be about 1 Calorie per hour higher than for Normal infants; for Underweight infants, the estimated heat production would fall outside the limit of plus 2 standard errors of estimate from the regression line for Normal infants; for Overweight infants, outside the limits of minus 2 standard errors of estimate.

[3] Computed from equation: Cal./hr. = 2.18 (weight, kg.) + 0.737; standard error of estimate = 1.6 Cal./hr.

[4] Computed from equations: For boys, Cal./hr. = 1.59 (weight, kg.) + 7.74; standard error of estimate = 2.2 Cal./hr.; for girls, Cal./hr. = 1.63 (weight, kg.) + 6.48; standard error of estimate = 1.9 Cal./hr.

values may be used to predict the heat production of infants while asleep and after feeding for the age intervals 1 week to 10 months and 11 to 38 months. The equation derived from the combined data for the respective age intervals (*see* figure 14) were used for computing these values.

For newborn infants, the regression lines were similar in slope, but the elevation of the lines was significantly different, perhaps, because of a difference in selecting the final test value. Therefore, estimates of heat production are not given for newborn infants, but may be obtained by either equation given in table 4—the choice to be made in accord with the procedure most representative of that used by a specific laboratory.

Since various degrees of prematurity were represented in the infants measured, the data were not considered homogeneous. Therefore, tables for predicting heat production of premature infants were not prepared.

V. Summary

A total of 656 measurements on Healthy full-term infants from birth to 3 years and 151 measurements on Premature infants were analyzed. "Basal" metabolic measurements on infants are usually made while asleep and after feeding in contrast to measurements on older children and adults made while awake and at least 12 hours after eating.

The weight-for-height classification previously established for children 2 years of age to puberty was applicable to Healthy infants 11 months of age and older. But since weight for height increased at a much faster rate in younger infants, a different weight-for-height classification was established for infants from birth to 10 months of age, inclusive. This classification was based on the line of average relationship of weight (on a logarithmic scale) for height (on an arithmetic scale) for infants from 1 to 10 months of age. The line of average relationship indicated that for infants up to 10 months of age, weight increased at the constant rate of 4.7 percent per centimeter increase in height; thereafter, the rate of increase was 1.8 percent.

Three linear regression equations were derived from the data to represent heat production in relation to weight from birth to 3 years of age. The time of change from one equation to another, although defined by average chronological age, coincided with physiological changes. Heat production was relatively low for Newborn infants. After 1 week of age, presumably when the infant had become adjusted to the extrauterine environment and growth was progressing satisfactorily, heat production increased at the constant rate of 2.2 Calories per hour per kilogram increase in weight up to, and including, 10 months of age. During the next age interval 11 to 38 months, the heat production rate was reduced to 1.6 Calories per hour per kilogram of weight.

The increase in heat production per unit increase in weight was the same for infants within the Slender and Normal weight-for-height classifications, but the regression line for the Slender was at a significantly higher elevation (except for Newborn infants). Sufficient measurements for Stocky and Overweight infants were not available for statistical analysis, but the data indicated that for *a given weight*, heat production in these infants was somewhat lower than that for Normal infants. Likewise, it was estimated that heat production of Underweight (undernourished) infants was somewhat higher than for Normal infants but increased at about the same rate in relation to weight as long as they were maintaining the same weight-for-height relationship.

These results support the theory that heat production is related to the amount of active protoplasmic tissue. As compared with Normal infants, Underweight and Slender infants weighed less for a given height; therefore, had a relatively greater proportion of active protoplasmic tissue per unit weight and a higher heat production. Similarly, Overweight infants weighed more for a given height than Normal infants; therefore, had a relatively smaller proportion of active protoplasmic tissue per unit weight, and a lower heat production.

The analysis of the data on premature infants gives additional support to this theory. The steeper slope (near 3.0) of the regression line relating heat production to weight indicated that for any given increase in weight, heat production increased at a faster rate in premature infants than in full-term infants. This is in line with their more rapid growth rate and with their rather rapid shift from Underweight toward a Normal weight-for-height classification with advancing age. (Healthy full-term infants usually maintain the same weight-for-height relationship for an indefinite time.)

A sex differentiation in heat production was not evident below 10 months of age, but following this age, heat production per given weight was higher for boys than for girls. However, the rate of increase in heat production in relation to weight was the same (at least the difference was not statistically significant).

The analyses of data available in the literature indicate that sleep depresses heat production to a greater extent—about 15 percent—than the ingestion of food increases it—about 8 percent—and that the effect of one is not counterbalanced by the effect of the other.

Tables for predicting heat production of full-term infants from 1 week to 3 years of age have been prepared from the regression equations derived from the data analyzed herein. A prediction table for premature infants was not prepared because of the range in the degree of prematurity of the infants.

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VII. Appendix—Results of Covariance Analysis

The analysis of covariance as outlined by Snedecor (1956) was used for the following tables (11 to 15).

TABLE 11.—BOYS WITH GIRLS: *Comparison of the regression of heat production on weight within three age intervals*

[Normal weight-for-height classification.]

Age interval	Investigator(s)	Source of variation	Deviations from regression	
			D.f.	Mean sq.[1]
Under 1 week (fed)	Benedict and Talbot (1915).	Pooled variation from individual regressions	35	0. 1289
		Difference in regression coefficients	1	. 0144
		Variation from common regression	36	. 1257
		Difference in adjusted means	1	. 0528
1 week to 10 months	Benedict and Talbot (1921).	Pooled variation from individual regressions	75	2. 468
		Difference in regression coefficients	1	. 014
		Variation from common regression	76	2. 436
		Difference in adjusted means	1	. 926
1 week to 10 months	Lee (1952)	Pooled variation from individual regressions	105	2. 32
		Difference in regression coefficients	1	2. 65
		Variation from common regression	106	2. 32
		Difference in adjusted means	1	. 20
11 months to 3 years	Lee (1952)	Pooled variation from individual regressions	126	4. 25
		Difference in regression coefficients	1	1. 42
		Variation from common regression	127	4. 23
		Difference in adjusted means	1	*20. 77

[1] *Indicates significance at the 5-percent level.

TABLE 12.—FED WITH NOT-FED INFANTS: *Comparison of the regression of heat production on weight for infants under 1 week old*

Age interval	Investigator(s)	Source of variation	Deviations from regression	
			D.f.	Mean sq.[1]
Under 1 week	Benedict and Talbot (1915).	Pooled variation from individual regressions	60	0. 215
		Difference in regression coefficients	1	. 005
		Variation from common regression	61	. 211
		Difference in adjusted means	1	**9. 031

[1] **Indicates significance at the 1-percent level.

Table 13.—Normal with Slender weight-for-height classification: *Comparison of the regression of heat production on weight for infants within three age intervals*

Age interval	Investigator(s)	Source of variation	Deviations from regression	
			D.f.	Mean sq.[1]
		Boys and girls		
Under 1 week (fed)	Benedict and Talbot (1915).	Pooled variation from individual regressions	49	0. 149
		Difference in regression coefficients	1	. 016
		Variation from common regression	50	. 146
		Difference in adjusted means	1	. 009
1 week to 10 months	Benedict and Talbot (1921).	Pooled variation from individual regressions	93	2. 32
		Difference in regression coefficients	1	. 17
		Variation from common regression	94	2. 30
		Difference in adjusted means	1	*10. 15
1 week to 10 months	Lee (1952)	Pooled variation from individual regressions	126	2. 27
		Difference in regression coefficients	1	1. 34
		Variation from common regression	127	2. 26
		Difference in adjusted means	1	**38. 24
		Boys		
11 months to 3 years	Lee (1952)	Pooled variation from individual regressions	74	4. 45
		Difference in regression coefficients	1	8. 32
		Variation from common regression	75	4. 50
		Difference in adjusted means	1	2. 77
		Girls		
11 months to 3 years	Lee (1952)	Pooled variation from individual regressions	87	3. 87
		Difference in regression coefficients	1	4. 77
		Variation from common regression	88	3. 88
		Difference in adjusted means	1	**44. 78

[1] *Indicates significance at the 5-percent level; **indicates significance at the 1-percent level.

TABLE 14.—HEALTHY INFANTS MEASURED BY DIFFERENT INVESTIGATORS: *Comparison of the regression of heat production on weight*

[Data for boys and girls combined.]

Age interval	Investigator(s)	Source of variation	Deviations from regression D.f.	Deviations from regression Mean sq.[1]
		Normal and Slender weight-for-height classification		
Under 1 week	Benedict and Talbot (1915) with Murlin *et al.* (1915 and 1925.)	Pooled variation from individual regressions	79	0. 206
		Difference in regression coefficients	1	. 014
		Variation from common regression	80	. 204
		Difference in adjusted means	1	**2. 625
		Normal weight-for-height classification		
1 week to 10 months	Benedict and Talbot (1921) with Lee (1952).	Pooled variation from individual regressions	184	2. 35
		Difference in regression coefficients	1	7. 50
		Variation from common regression	185	2. 38
		Difference in adjusted means	1	3. 52
		Slender weight-for-height classification		
1 week to 10 months	Benedict and Talbot (1921) with Lee (1952).	Pooled variation from individual regressions	35	1. 98
		Difference in regression coefficients	1	5. 05
		Variation from common regression	36	2. 07
		Difference in adjusted means	1	4. 95

[1] **Indicates significance at the 1-percent level.

TABLE 15.—PREMATURE INFANTS MEASURED BY DIFFERENT INVESTIGATORS OR LABORATORIES: *Comparison of the regression of heat production on weight*

[Data for boys and girls combined.]

Age interval	Investigator(s)	Source of variation	Deviations from regression D.f.	Deviations from regression Mean sq.[1]
Birth to 10 days, inclusive.	Marsh and Murlin (1925) with Cornell University Medical Laboratory (1936, 1943).	Pooled variation from individual regressions	43	0. 405
		Difference in regression coefficients	1	1. 104
		Variation from common regression	44	. 421
		Difference in adjusted means	1	**5 408
11 days and older	Talbot *et al.* (1923) with Cornell University Medical Laboratory (1936, 1940, 1942, 1943).	Pooled variation from individual regressions	77	. 367
		Difference in regression coefficients	1	. 193
		Variation from common regression	78	. 365
		Difference in adjusted means	1	**8. 287

[1] **Indicates significance at the 1-percent level.

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